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EDITORIAL NOTES.

THE Council of the Geological Society has made the following awards for 1923: Wollaston Medal, Mr. William Whitaker, B.A., F.R.S.; Murchison Medal, Dr. John Joly, F.R.S.; Lyell Medal, M. Gustave F. Dollfus; Bigsby Medal, Mr. Edward Battersby Bailey, M.C., B.A.; Wollaston Fund, Mr. Herbert Harold Read, B.Sc.; Murchison Fund, Mr. Thomas Henry Withers; Lyell Fund, Professor William Thomas Gordon, M.A., D.Sc., and Professor William Noel Benson, B.A., D.Sc.

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THE following members retire this year from the Council of the Geological Society: Dr. F. A. Bather, Mr. T. C. Cantrill, Professor E. J. Garwood, Mr. J. F. N. Green, and Dr. G. T. Prior. In their place the Council recommends the election of Dr. C. W. Andrews, Dr. Gertrude L. Elles, Dr. J. W. Evans, Dr. W. D. Lang, and Sir J. J. H. Teall. The retiring Vice-Presidents are Professor Garwood and Dr. Prior: to fill their places, Professor Watts and Dr. Evans are proposed.

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THE next meeting of the British Association for the Advancement of Science will be held at Liverpool from 12th to 19th September, 1923. The President of Section C, Geology, will be Dr. Gertrude L. Elles, of Newnham College, Cambridge.

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THE Foulerton Award of the Geologists' Association for the year 1923 has been given to Mr. A. S. Kennard, F.G.S. In conjunction with Mr. Martin A. C. Hinton he contributed to the *Proceedings* of the Association the important paper on "The Relative Ages of the Stone Implements of the Lower Thames Valley", and with Mr. B. B. Woodward several papers on the Post-Pliocene Non-Marine Mollusca of England and Ireland. He has also conducted excursions for the Association.

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THE Editor regrets that he is obliged to point out to contributors that of late a large number of proofs have been returned to him insufficiently stamped. At present, only one ounce can be sent for three-halfpence, and nearly all proofs require, at least, a two-penny stamp, which is the rate up to three ounces.

ORIGINAL ARTICLES.

On a Boring at Roddymoor Colliery, near Crook, Co. Durham.

By David Woolacott, D.Sc., F.G.S.

A BORING that was completed in 1921 by Messrs. Pease and Partners, at Roddymoor Colliery, near Crook, Co. Durham, about 5 miles north-west of Bishop Auckland, is of considerable importance. I had the good fortune to be consulted in connexion with the correlation of the strata in the lower part of the section, and was also allowed to make a thorough examination of the whole of the cores. The stratigraphical results are of much interest, and it is mainly with these I propose to deal in this paper. Mr. R. G. Carruthers, of H.M. Geological Survey, also examined the cores, and on his suggestion they were broken up and the fossils in them collected by Mr. Tate, of the Survey. It is hoped that when these are determined, results may be obtained which will aid the zonal classification and correlation of the Lower Carboniferous rocks of the two north-eastern counties.

It is the deepest boring that has been made in these counties, and it penetrated into lower strata than any previous one. Its object was to obtain information regarding the presence or absence of coals of workable thickness and quality in the Carboniferous Limestone series in Weardale. It was known that a particular development of this group in Northumberland—called by Professor Lebour the Bernician series—contains several seams, and although there was evidence that these decreased in thickness and deteriorated in quality when traced southwards towards Alston and Weardale, yet it could not be taken as definitely proved that the limestone series in Durham contained no coals of economic value. This boring would appear, along with the other evidence obtainable, to show that they do not. It was commenced at the bottom of the Emma Pit, at 289 feet below ground-level, and 191 feet below the Brockwell seam, i.e. the bed taken to mark the base of the Lower Coal Measures in the northern coalfield. It passed through 2,622 feet of strata, and as the 289 feet above the starting point belong to the Coal Measures and to the superficial deposits, the beds at this point may be said to be definitely known for 2,911 feet. It is not proposed in this paper to give a detailed statement of the minor divisions of the section, but rather to discuss the main features of general stratigraphical interest. Thin coals were found at one or two horizons, but in all cases they were only one or two inches thick. The whole of the Carboniferous strata were lying very flat, and except for occasional slickensiding of the shales there was little to indicate any disturbance of them.

The following are the chief divisions passed through. The height of the surface above sea-level was 651 feet. Lat. 54° 43′ 15″; long. 1° 46′.

Series.	*Section.*	*Thickness.*	*Depth from Surface.*	*Description.*
		ft. in.	ft. in.	
Superficial.		?		
Middle Coal Measures.	Brockwell Seam . .	?	99 0	
Lower Coal Measures, 258 ft. 9 in.	Commencement of boring .		289 0	Shales, fireclays, sandstones; with ironstone nodules in shales and fireclays.
	Base of Coal Measures .		357 9	
Millstone Grit, 459 ft. 5 in.	Sea-level . . .		651 0	Sandstones, gritty, coarse, felspathic, and calcareous; shales, fireclays, bed of ganister (4 ft. 7 in.), and three coals 1 in. in thickness. Bands with marine fossils near base.
		459 5	817 2	
Yoredale Rocks, 1,374 ft. 10 in.	Fell top Limestone . .	16 1		A series of limestones the chief of which are given (there are, however, many thinner intercalated limestones at different horizons), shales, fireclays, sandstones, and one or two thin beds of ganister, ironstone nodules abundant in shales and fireclays, veins of calcite and impregnations of pyrites common. Thin coals at two horizons. The Whin Sill is intruded into the Scar Limestone which is divided into two parts.
	Little Limestone . .	10 9		
	Smutty coal. . .	3		
	Great Limestone . .	60 8		
	Coal	2		
	Four Fathom Limestone .	17 0		
	Nattrass Gill Hazle .	84 6		
	Three Yard Limestone .	4 4		
	Five Yard Limestone .	28 0		
	Top of Scar Limestone .	7 3		
	Whin Sill . . .	187 1		
	Base of Scar Limestone .	15 6		
	Cockle Shell Limestone .	7 2		
	Single Post Limestone .	5 10		
	Tyne Bottom Limestone .	38 3		
	Jew Limestone . .	23 3	2,192 0	
Melmerby Scar Limestone Series, 553 ft. 2 in.	Little Limestone . .	18 5		Upper part similar to Yoredales, Limestone beds 17. Thickness 245 ft. 4 in.
	Smiddy Limestone . .	12 11		
	Robinson Limestone .	12 0		
	Representatives of Melmerby Scar Limestone.	171 6		Thick limestones interbedded with fireclays, shales, and sandstones. Nodular limestones. Pyrites disseminated in several beds.
	Thin limestones, shales, sandstones, and grit.	136 2		These limestones, shales, and sandstones are passage beds between the conglomerates and the Melmerby Scar Limestone.
			2,745 2	

Series.	*Section.*	*Thickness.*	*Depth from Surface.*	*Description.*
Basement Conglomerate Series, 82 ft. 4 in.	Roman Fell Series of some authors.[1]		2,827 6	A series of quartz glomerates, quartzitic shales, thin fossilif limestones. At the b shale with fine q fragments.
Lower Palæozoic, 83 ft. 6 in.	Skiddaw Slates [2]		2,911 0	Slates, beds contorted, fo cleaved, and puck quartz veins, ta sericitic and gra partings. Garnetif bands on one horizon slates being schistose. fossils.

Several features of geological interest arise in connexion with this boring. The chief are :—

(1) From it a more or less definite thickness can be given to the Lower Coal Measures. I had little hesitation in separating the fine sandstones of these beds from the coarser grits and sandstones of the Millstone Grit series. If this line of demarcation is correct, the Lower Coal Measures are 250 feet in thickness. No ganister occurred in them, nor were any marine fossils obtained.

(2) The Millstone Grit is a series of grits, sandstones, shales with and without ironstone nodules, fireclays, one bed of ganister (4 feet 7 inches), and three 1 inch layers of coal. The most important feature is the occurrence in the lower part, above the Felltop Limestone, of two or three bands with marine fossils. These are similar in position to the Botany Beds—impure limestone and calcareous shales—described by Professor Garwood [3] and well exposed in a quarry near Hury in Baldersdale, and they therefore most probably belong to the upper *Dibunophyllum* zone, D_3. The conditions of deposition of the lower Millstone Grit series in Weardale and Teesdale must have been the same. As far as I am aware, no marine fauna occurs in the Millstone Grit at any point to the north of Weardale although marine fossils were found at Whittonstall in the Lower Coal Measures by Professor Lebour in 1878.[4]

(3) The total thickness of the Carboniferous Limestone at Crook is 2,010 feet. It is interesting to compare this with that known at other points in the two north-eastern counties.

[1] See par. 9.
[2] See par. 10.
[3] *Q.J.G.S.*, vol. lxviii, 1912, p. 543.
[4] Geol. Mag., March, 1878.

	Teesdale.	*Weardale.*	*Alston.*	*Mid-Northumberland.*	*North Northumberland.*
Thickness of Carboniferous rocks beneath the Felltop Limestone . .	1,400	2,010	2,500 +	8,000 +	5,000

There is thus a marked and continuous thickening as the beds are traced north from Teesdale to Mid-Northumberland, followed by a thinning as they are followed further north. Two or three explanations of this are possible, and these I propose to discuss briefly.

(1) In order to explain the thickening of the Carboniferous rocks as they are traced southwards along the Pennine escarpment in the Vale of Eden, Goodchild suggested that there existed an east and west Pre-Carboniferous ridge, which ran through the Lake District and across Durham.[1] It was formed of Lower Palæozoic rocks, folded, cleaved and faulted by the Caledonian movements. In Jukes Browne's *Stratigraphical Geology*[2] there is a map showing the position of this hypothetical ridge. It is evident that if it did exist, the thickening of the Carboniferous Limestone rocks we are discussing, especially that near their base,[3] would be, in part, satisfactorily explained. Professor Garwood has, however, shown that "the lowest deposits met with in the north-western province occur in close proximity to the Lake District". The Lake District was probably submerged by the Carboniferous sea before the Crossfell region and the counties of Northumberland and Durham, and these before the Ingleborough and Penyghent area, so that it would appear that the cause of the thickening of the Lower Carboniferous strata in the North of England is not to be found in the existence of a Pre-Carboniferous Lake District–Durham ridge. Lagoon conditions of deposition appear to have begun in the Lake District, followed shortly after by similar conditions in Northumberland. In these lagoons calcareous algæ flourished. They have been found in the Rothbury Limestones by Professor Garwood and Mr. P. L. Robinson, and in a bed above the Woodend Limestone (Bernician Series) in the Scremerston district by Mr. E. Merrick and by Professor Garwood in the Shap area.

(2) Mere thickening of deposits near a shore-line does not appear to explain this particular case, as the chief limestone beds in the upper part are traceable from Teesdale into Northumberland, occurring at intervals in the strata and the intervening beds

[1] Both Professors Marr and Garwood consider that the area of the Lake District was not a relatively upraised one at the beginning of Carboniferous times. Marr, *Geology of the Lake District*, p. 111; Garwood, *Q.J.G.S.*, vol. lxviii, 1912, p. 554.

[2] Second edition, 1912, p. 260.

[3] e.g. the thickness of the beds beneath the Jew Limestone in Teesdale is 428 ft., at Crook 636 ft., and at Alston 1,537 ft., and in Mid-Northumberland the beds on the same horizon must be at least 4,000 ft.

swelling out between them in Mid-Northumberland. At Crook the thickness of the strata between the Felltop and the Little Limestones is 114 feet, and is mainly shale, while in Mid-Northumberland the thickness has increased to 1,200 feet and is chiefly grits and sandstones.[1]

(3) The great increase in the amount of sedimentation and the marked change in the nature of the deposits (discussed in paragraph 6) thus appears to demand that the central part of Northumberland was a relatively more rapidly sinking area than the rest of the North of England, so that a basin was formed in which a particular type and thickness of sedimentation was laid down. It would appear that we have here an illustration of the continuous sinking of an area brought about by the weight of the relatively coarse and thick sediments laid down in it, i.e. an example of the isostatic adjustment of the crust to the weight accumulating on it. The mainland, which was probably a rising area, lay to the north (i.e. the Caledonian Chain of the ancient continent of Arctis); it is, however, a peculiar feature of the Lower Carboniferous of Mid-Northumberland that the sediments in it are not only coarser and thicker than those on the south, but that there is also a greater development of coarser arenaceous strata in the upper beds than there are in the beds of the same age in the Lowlands of Scotland. This is probably owing to the fact that the areas of the Cheviots and Southern Uplands of Scotland were not completely covered by sediment until quite late in Lower Carboniferous times. A great part of the sediment laid down in the early Carboniferous period was derived from these areas which were gradually being submerged.

(4) The base of the Yoredale Rocks is taken at the bottom of the Jew Limestone, which is the equivalent of the Hardraw Scar Limestone of Yorkshire.[2] The latter bed was adopted by Phillips as the lower line of demarcation of these beds in the region of their typical development. The Oxford Limestone of Northumberland is on or about the same horizon.[3]

Many intercalated limestones occur between the main calcareous beds in the Crook section, e.g. there are five thin bands of this character varying from 4 to 16 inches between the Felltop and the Little Limestones. These are similar in position to, but less in thickness than, the limestones intercalated between these strata north of the Tyne in Mid-Northumberland,[4] and proved by a boring to continue into the Derwent valley.[5] Between the Little

[1] The thickness between the Felltop and the Little Limestones in Teesdale is 360 ft., at Crook 114 ft., at Alston 350 ft., in Mid-Northumberland 1,200 ft., and at Broomhill, near Amble, 455 ft.

[2] S. Smith, "The Carboniferous Limestone Series in the North of England": *N. of Eng. Inst. Min. and Mech. Eng.*, 1912, p. 181.

[3] W. Gunn, GEOL. MAG., 1918, p. 342; and Garwood, "Geology of Northumberland and Durham": *Geology in the Field*, Geol. Assoc., 1910, p. 674.

[4] Lebour, *Trans. N. of Eng. Inst. Min. and Mech. Eng.*, vol. xxiv, p. 73.

[5] J. B. Simpson, *Trans. Inst. Min. Eng.*, vol. xxiv, p. 549.

and the Great Limestones there were eight such beds, one of them 10 feet 4 inches in thickness. All these are absent in the Alston district, but in the Broomhill boring (Northumberland) some minor limestones do occur in the same position. In the Alston district, the number of calcareous beds in the Yoredales is about fifteen, but at Crook they have increased to thirty-five.

CORRELATION OF THE CARBONIFEROUS LIMESTONE SERIES (AVONIAN) IN THE RODDYMOOR BORING WITH THAT OF NORTHUMBERLAND.

Roddymoor.[2]	*Northumberland.*		*Zones.*[1] (1)	*Zones.*[1] (2)
Yoredale Rocks, 1,375.	Calcareous division, 1,600–4,000.	Bernician[3].	D	D_2
				D_1
Melmerby Scar Limestone, 553.	Carbonaceous division, 500–2,500.		C	S_2
				S_1
Basement Conglomerate, Series,[4] 83.	Fell Sandstones, 500–2,000.		B	C_2
	Cementstone and Rothbury Limestone group. Lower Freestones, 500–3,000.	Tuedian.	A	C_1

The Great Limestone, which is the thickest calcareous bed in the boring, is 60 feet thick. In Northumberland it is usually 25–30 feet, thickening, however, southwards to over 40 feet near Matfen. At Alston it is 63 feet, while in the quarries at Stanhope, where it reaches its most important development, it is 72 feet thick.

[1] Zones as given by Professor Garwood, *Q.J.G.S.*, vol. lxviii, 1912, p. 547.
(1) Zones of North-Western Province :—
D. *Dibunophyllum.*
C. *Productus corrugato-hemispherica.*
B. *Michelinia grandis.*
A. *Athyris glabristria.*
(2) Equivalent zones of South-Western province. The lowest zones are not represented.

[2] The zonal equivalents of the Durham Beds are not yet determined, but judging from the results obtained in the Pennine area, the Yoredale Rocks are D_2, the Melmerby Scar Limestone S_2 and D_1. The lowest zone to which the Basement conglomerate goes is not known, but such beds go down to C_1 on the escarpment, and if this is so at Roddymoor, then the 80 feet of rock there must be homotaxial with many hundreds of feet in Northumberland. It will be interesting to see how far the examinations of the fossils collected verifies the correlation in this table.

[3] I have purposely omitted the exact line of demarcation between the Tuedian and Bernician, as this paper is not the place to discuss the limits of these formations.

[4] Roman Fell Series of Lebour ; see par. 9.

(5) The only coals that occurred in the whole of the Carboniferous Limestone series are in the Yoredale Rocks, viz. a smutty coal of 3 inches (with a shale with coaly partings above and below it, making 18 inches in all) lying 269 feet below the Little Limestone and 24 feet above the Great, and a 2-inch coal band 9 feet below this bed. The former corresponds roughly in position with the low coal sill proved at Alston, between the Little and Great Limestones; the latter is the Great Limestone coal, which is a tolerably constant seam further north. The Shilbottle, Beadnell, and other seams of the calcareous division of the Bernician in Northumberland were not proved, nor are there any representatives of the Scremerston, Plashetts, or Lewisburn coals, nor of the seams proved at Alston between the Felltop and the Little, and beneath the Scar and Melmerby Scar Limestones. It is definitely proved by this boring that the limestone coals in the two north-eastern counties thin out to the south and east.

(6) Taking a survey of the whole Lower Carboniferous beneath the Felltop Limestone, one or two points of interest are deducible. In the 2,000 feet of strata about 550 feet are calcareous, 350 feet arenaceous, and 1,100 feet are argillaceous. The total number of calcareous beds is about seventy-five, which is a marked increase in their number as compared with the development of these rocks on Crossfell, at Alston or in Northumberland, and I also think that the ratio of the calcareous to the mechanically-deposited sediments is much greater than in any of these areas.

When a comparison is made between the proportion of the shales to the sandstones, it is found that the finer sediments are more predominant at Roddymoor than elsewhere in the two north-eastern counties. At Alston the shales and sandstones are about equal in thickness,[1] while in Northumberland the sandstones and grits form a most conspicuous feature of these rocks, e.g. 1,200 feet of strata lying above the Little Limestone in the Matfen district (Mid-Northumberland) is practically made up entirely of sandstones and grits, often coarse-grained and conglomeratic [2] (Inghoe Grits of the Inghoe, Rothley and Shaftoe Crags), and the Fell sandstones reach 2,000 feet near Rothbury, and are mainly arenaceous strata. In the Crook boring the sandstones were usually fine-grained and, with the exception of the Basement conglomerates, there was little development of coarse sediment. The thickest sandstone passed through was 84 feet 6 inches, lying beneath the Four Fathom Limestone and corresponding roughly in position with the Nattrass Gill Hazle of Weardale.[3] The Inghoe Grits, Prudham Stone, and the Fell Sandstones of Northumberland had no distinct representatives. The strata passed through in this boring prove that the Carboniferous sea was deeper to the south and east in

[1] Lebour, *Geology of Northumberland and Durham*, p. 60.
[2] Ibid., p. 60.
[3] Westgarth Forster's *Section of the Strata*, p. 97.

Northumberland and Durham during the deposition of the later Carboniferous Limestone series; the sediments laid down were finer and the beds more calcareous in these directions.

(7) The Great Whin Sill occurs in the Scar Limestone dividing this bed into two distinct parts. The section proved was:—

	ft.	in.
Limestone, base saccharoidal . . .	7	3
Whin Sill, with compact micro-crystalline top	187	1
Limestone, encrinital, with veins of calcspar .	15	6

Its stratigraphical position differs from that at several other points, e.g. in Teesdale it is near the base of the Limestone series; in High Cup Gill, at Alston, in the Slitt Mine and the Burtree Pasture Mine it is beneath the Tyne Bottom Limestone (which was at one time called the Whintop Limestone); at Greenhead it is near the Great Limestone, at Elf Hills quarry, near the Four Fathom Limestone; and at Craster under the Great, while further to the north near Kyloe it is some 800 feet above this limestone. Its shift in position among the beds is 2,000 or 3,000 feet. (The thickness of the Carboniferous rocks varies so much between Teesdale and Kyloe that it is impossible to estimate this exactly. It, however, shifts its horizon from beneath the Melmerby Scar Limestone to near the top of the Limestone series.)

Its thickness at Crook is one of the greatest recorded. At Burtree Pasture Mine it is about 240 feet; at Carr Edge Mine, Northumberland, it is 222 feet; and in Teesdale it reaches 200 feet near Cronkley Scar. Its average thickness is from 80 to 100 feet, but it thins out westwards on the Pennine escarpment to 6 feet (Rundale Beck).

This occurrence proved at Crook is many miles east of any previously known in Durham, and is within 8 miles of its most easterly exposure in Northumberland. Its outcrop on the Pennine escarpment is 25 miles to the west of Crook. Professor Lebour states that it probably underlies 400 square miles of country, and must represent at least 8 cubic miles of rock. This boring proves that this is not an exaggerated estimate. The fissure up which it came must lie to the east of Crook.

The texture of the Whin Sill shows considerable variation, varying from a coarse-grained rock, somewhat similar to the gabbro-like variety occurring above Cauldron Snout in Teesdale, through the usual fine, even-grained, doleritic type, to a compact micro-crystalline basaltic rock near the margin. The coarse-textured rock occurs near the middle of the sill, being 4 or 5 feet in thickness. Both the augite and felspar crystals are needle-shaped, and reach 1 inch in length. It is even coarser than that at Cauldron Snout. The limestones, both beneath and above it, were altered; the lower is filled with calcspar veins, and the upper is distinctly crystalline and saccharoidal.

The two divisions of the Scar Limestone total 22 feet 9 inches, which is about the usual thickness of this bed (e.g. in Teesdale

it is 22 feet, in Weardale 25 feet, at Alston 30 feet), so that it would appear that no argument in favour of the Whin Sill assimilating any of the strata through which it passed can be based upon this section.[1] If any assimilation did take place, which appears to be very improbable, it cannot have been more than a few feet of rock.

The Little Whin Sill, which is a thin sheet about 30 feet in thickness, does not occur in this boring. It is quarried near Stanhope, where it lies between the posts of the Three-yard Limestone at a higher horizon than the Great Sill.[2] It has been proved to have a very limited westerly extent, and this boring shows that it does not occur far to the east of Stanhope. This minor sill would appear to be an offshoot of the larger one, with which it is identical in petrographical characters.[3]

Suess in *Das Antlitz der Erde*,[4] when referring to the intrusion of the Great Whin Sill, doubts if a force exists at so great a distance from the centre of eruption capable of elevating strata thousands of feet thick and yet vested in a mass of igneous rock of no considerable bulk. He suggests that it is probable that it lies in the course of an oblique fracture—a fault or thrust-plane—which followed for long distances the dip of the strata but with repeated "jumps" to other horizons, the inflowing basalt being "injected" along this great fracture. There is, however, no evidence for the existence of such a dislocation prior to the intrusion of the Whin Sill. Nowhere along its course, or in borings that have been made through it, is there either above or below it any zone of fracture or flowage or metamorphism (except such as can be proved to be distinctly due to contact with the Sill). It would appear impossible for an extensive oblique fracture of the nature suggested by Suess to have existed without being marked by such a zone. I consider this great intrusive sheet to have been intruded at the end of the Carboniferous period, and to be one of the results of the Armorican and Pennine system of movements that took place then. The line of the fissure up which the intrusion came appears to have lain on the flank of the great syncline of the Northumberland and Durham pre-Permian rocks which were downfolded, the Whin Sill being forced up westwards between the beds of the uplifted anticline or monocline of the Pennine and Cheviot areas. The force is derived from the movements of the outer crust, the downfolded strata acting on the magma of the sub-crust and forcing the molten rock up the line of least resistance. At least 8 cubic miles of rock must have been intruded.

(8) The base of the Yoredale Rocks is taken at the Jew Limestone, although for about 250 feet beneath it there is much the same

[1] Clough is of the opinion that there is evidence of much assimilation in Teesdale, GEOL. MAG., 1880, p. 433.

[2] W. M. Egglestone, "Geology of the Little Whin Sill": *Trans. Inst. Min. Eng.*, vol. xxxix, pt. i.

[3] J. J. H. Teall, "On the chemical and microscopical characters of the Whin Sill": *Q.J.G.S.*, vol. xl, 1884, p. 654.

[4] See *The Face of the Earth*, vol. i, p. 154.

alternation of limestone and shale. As, however, this stratum is correlated with the Hardraw Scar Limestone, it was adopted as a base line, although there was no distinct lithological change.

The calcareous beds, however, thicken and become more numerous below 2,437 feet, and the Melmerby Scar Limestone facies distinctly sets in.

There is no thick and massive bed of limestone as on the Pennine escarpment, where one bed reaches at least 150 feet, but there is a series of calcareous beds, varying in thickness from 42 feet to 6 feet between 2,437 feet and 2,609 feet, there being 130 feet of limestone in the 170 feet of rock. This probably represents the main stratum of the Melmerby Scar Limestone.

At Alston, the total thickness of beds beneath the Jew Limestone is 1,500 feet, and the Melmerby Scar Limestone proper is 185 feet, but the proportion of shales and sandstone to limestone is much greater than at Crook, where the beds in a similar position are only 553 feet thick. In Teesdale, the equivalent strata are less than 400 feet thick, the Melmerby Scar Limestone series being somewhat similar to that at Crook, but the rocks on the same horizon in Northumberland are entirely different, being argillaceous and arenaceous strata with thin limestones and coal seams, i.e. the lower Calcareous and the Carbonaceous divisions of the Bernician Series.

Two limestones in the Crook boring on this horizon are peculiar, consisting of nodules of limestone embedded in light grey shale or fireclay (Nodular Limestone). They were recorded by the borer as Honeycomb Limestone. Although the limestone has a distinctly brecciated appearance it is difficult to understand how a contemporaneous breccia of this type could be formed under the conditions in which the rocks were laid down. I have not yet decided how this bed was formed, but hope to do so by further examination of it.

(9) The Basement Conglomerate Series is 82 feet thick. They consist of interbedded quartz conglomerates, quartzitic grits, shales, and thin fossiliferous marine limestones. The conglomerates are never very coarse, and are not polygenetic, the only pebbles in them being quartz and fragments of slate, both derived from the underlying Lower Palæozoic rocks. The beds are fossiliferous, and it ought to be possible to fix the zone to which they belong when the fossils have been determined; beds occupying an exactly similar position on the Pennine escarpment are known to belong to the *Athyris glabristria* zone.[1] I have called these beds the Basement Conglomerate series, although they are the representatives of the sandstones and conglomerates that are usually named the Roman Fell series.[2] There is, however, some doubt regarding the exact

[1] Garwood, *Q.J.G.S.*, vol. lxviii, 1912, p. 537.

[2] Professor Lebour, *Geology of Northumberland and Durham*, p. 51, and Geol. Surv. Map, New Series, sheet 31.

significance of this term. Professor Garwood has shown that the conglomerates on the top of Roman Fell are not the same as the beds generally called the Roman Fell series along the base of the Pennine escarpment.[1] I agree with this, and, indeed, had noticed the difficulty independently, many years ago. The conglomerates forming the top of Roman Fell would appear to be of the same character and to have been formed under the same conditions as the Mell Fell conglomerates of the Lake District and the Windy Eyle and Roddam Dene conglomerates of the Cheviots. The lowest beds at Crook are later than these, and were formed under marine conditions, being the product of wave action on the submerging Old Red Sandstone land-surface. I have called these strata the Basement Conglomerate series, and as long as it is understood that the conglomerates at the base of the Carboniferous may have been formed at different times, there should be no difficulty. The term Roman Fell series is bad, as these conglomerates are not really those developed on Roman Fell.

Near the base of this series was a limestone with quartz pebbles, and at their base was a shale full of small fragments of quartz—the latter undoubtedly derived from the veins of that mineral in the argillaceous Lower Palæozoic rocks beneath. These beds are 82 feet thick, the section being of the following character :—

	ft.	in.
Grey quartzitic grit	16	5
Quartz conglomerate	3	5
Quartzitic grit with pyrites	2	4
Quartz conglomerate	2	5
Grey shale, fossiliferous	15	1
Limestone	2	0
Grey and blue shale	11	0
Limestone	2	9
Grey sandstone	1	0
Limestone	1	0
Grey sandstone	3	0
Shale		10
Limestone		5
Blue shale		5
Limestone		5
Limestone with quartz fragments		4
Shale		11
Calcareous shale	3	4
Shale, fossiliferous	1	4
Limestone	2	0
Limestone with quartz pebbles		9
Limestone with shaly partings	4	6
Calcareous shale with fine quartz fragments	4	7

Unconformity.

(10) The strata lying beneath the unconformity consist of light and dark grey argillaceous rocks, the latter being the much more prominent type. They contain thick irregular quartz veins, which may have been deposited contemporaneously with them in the form

[1] Ibid., p. 536.

of siliceous sinter from springs. The original bedding can be distinctly seen in them; it is highly contorted in places, and the beds obviously form a part of a series of highly folded strata. They are also highly cleaved, two very distinct planes being developed subsequent to the contortion and folding of the strata. Part of the light grey rock has thin garnetiferous bands developed in it, the rock passing into a true garnetiferous schist. The lighter coloured beds may have originally been more calcareous than the darker variety; the garnet being developed by dynamic metamorphism in the more calcareous layers. The cleavage planes and other lines of fracture have sericitic, talcose, and graphitic partings developed along them. The beds have, therefore, undergone considerable metamorphism. Subsequent to the development of the cleavage, the rocks have been subjected to further pressure, as the planes of cleavage are finely waved and in places very minutely puckered. These rocks bear evidence of the action of intense pressure; they have been contorted, folded, rendered schistose, cleaved, and the fracture-planes have been waved and puckered. These were all probably developed by the action of one continuous pressure, which varied in intensity from time to time; the sequence of results being contortion, folding, cleaving, metamorphism, and puckering of the strata. These are the direct result of the Caledonian series of movements, which had such marked effects on the whole of the Lower Palæozoic rocks of the north of England and the south of Scotland; the pressures acted from north-west to south-east, the cleavage and axes of the folds trending from north-east to south-west.

These rocks are unfossiliferous; it is therefore impossible to determine their age definitely. When I first examined them I concluded that they were Skiddaw Slates, which rocks they certainly resemble in colour, cleavage, and general characters, and in the occurrence in them of quartz veins (e.g. they may be compared with the Skiddaw Slates of the Cross Fell Inlier). Dr. Trechmann subsequently examined them and agreed with this determination. Some specimens were sent to Cambridge, and were examined by Professor Marr, Dr. G. L. Elles, Dr. Rastall, and Mr. T. C. Nicholas, who all agree that lithologically they correspond very closely with the uppermost black shaly portion of the Skiddaw Slates. They are, however, too much crushed to afford any prospect of the discovery of determinable graptolites, which otherwise might be expected in rocks of this type. I think they may be definitely accepted as being these rocks, and are thus of Lower Ordovician or Upper Cambrian age. The oldest rocks seen in Northumberland and Durham are Silurian—Wenlock in the Cheviots and Tarannon? in Teesdale.

The depth of the floor of Lower Palæozoic rocks at Roddymoor is 2,276 feet below sea-level. The floor of Northumberland and Durham was a land-surface before the deposition of the Carboniferous rocks, and considerable irregularities must have existed upon

it, but it was planed down by the sea as it was gradually submerged. Subsequent movements of the crust (mainly, perhaps, the depression of the Central Northumberland area suggested in paragraph (1) while the Lower Carboniferous were being deposited, and the later uprise of the Pennines and of the Cheviots area) has rendered its relative levels very different from what they originally were. The approximate present levels of the Lower Palæozoic floor are at the base of Crossfell 1,000 feet, in Teesdale and the Cheviots 1,600 feet above sea-level; while at Crook it is 2,276 feet below. The gradient of this floor from Crossfell to Crook is about 3,200 feet in 25 miles, or 1 in 40. It must lie at least 5,000 feet beneath the surface at Hartlepool and Sunderland.

I desire to thank Messrs. Pease and Partners for granting me leave to publish the results of this boring, and Mr. Pratt, manager of Roddymoor Colliery, for aiding me in every way possible in the examination of the cores.

The Nomenclature of the Spilitic Suite. Part II: The Problem of the Spilites.

By A. K. Wells, M.Sc., F.G.S.

I. Introduction.

ALTHOUGH spilite as a rock name has been in use for nearly a hundred years, there are few rocks, probably none of equal importance, so incompletely understood. Introduced in 1827 by Brongniart, "spilite" was first used officially in this country by Flett when describing the pillow-lavas of South Devon (Plymouth and Liskeard Memoir, 1907), and has now completely replaced the indefinite terms "greenstone" and "epidiorite", by which these lavas were formerly known. It is only quite recently that the importance of spilite has been properly appreciated. The progress of research has shown that at several different geological periods lavas of spilitic type have been almost completely dominant in Britain. Typical spilites and keratophyres were extruded in Pre-Cambrian times over a very extensive area, remnants of the flows being preserved in Argyllshire (Tayvallich and Loch Awe), and in Anglesey, localities which must have been far removed from one another at that time. Throughout Ordovician times the basic lavas were almost without exception spilites or closely allied types. The best known examples of spilites in Britain are those occurring abundantly in the Devonian and lower part of the Carboniferous rocks of South-West England, so ably described by Dewey and Flett, to whom most of our knowledge of these rocks is due. To deny the important rôle of spilite in the history of igneous activity in this country is no mere difference of opinion, but a denial of fact. Yet there are many who, with the American geologists, deny not only the importance, but even the existences

of the rock. The other extreme of opinion is found in those who see in the spilitic rocks a series whose petrogenesis presents problems of more than usual interest and which they have elevated to occupy a position comparable in importance with the better known calcic and alkalic suites.

During the eleven years which have passed since the attention of British geologists was first directed to these rocks,[1] numbers of papers have been published dealing with different aspects of the subject, and revealing to the reader differences of opinion on essential points concerning the field relations and petrogenesis of spilites. These differences of opinion, the absence from standard text-books of adequate accounts of spilite, and the growing interest shown in the rock by an increasing number of workers, are the author's reasons for attempting a statement of our knowledge of this Cinderella of the basic lavas.

II. Field Relations.

The most characteristic external feature of spilites, and that which first attracted the attention of geologists to them, is the pillow structure so frequently and so perfectly developed in them. This structure and the physical characters of spilites are too well known to justify further description here. When describing the spilites of the Mona Complex, Anglesey, Greenly mentions "boss after boss . . . built up entirely of these curious pillow bodies, often with small interspaces . . . often pressing one another's sides into gentle re-entering curves that impart a strangely vivid sense of softness, and suggest the rolling over and over each other of pasty masses kept from adhering by immersion in such a medium as the water of the sea".[2] Dewey pictures the physical condition of the spilite flow to have been such that "the whole sheet, composed of large nearly solid spheres, must have moved like a liquid". We are to imagine "a mobile sheet of flowing spheres (of lava) more or less surrounded by escaping steam, seldom touching one another until they cooled".[3]

A detailed discussion of the causes of pillow structure in lava is beyond the scope of this paper, but it is thought that a summary of recent views on the subject may prove of interest.

A Canadian writer, M. E. Wilson, lays stress upon the similarity between the pahoehoe structure of sub-aerial flows and the pillow structure developed by submarine lavas, and is evidently of the opinion that lava in a suitable condition for the formation of pahoehoe on land would, if extruded under water, assume the pillow habit.[4] From the cooling surface of a basic flow innumerable miniature rivulets of extremely hot and very fluid lava issue under pressure from the many cracks continually forming in the crust.

[1] Dewey and Flett, Geol. Mag., 1911, p. 202.
[2] Greenly, "Geol. of Anglesey": *Mem. Geol. Surv.*, 1919, vol. i, p. 71.
[3] Dewey, "Geol. of N. Cornwall": *Proc. Geol. Assoc.*, 1914, p. 166.
[4] Wilson, *Geol. Surv. Canada*, Mem. No. 39, 1914, p. 5.

On account of their fluidity these diminutive flows spread out very thinly and are quickly cooled, to be covered by a succession of later small flows behaving in the same way. This process has been observed again and again when basic lavas have been extruded sub-aerially. Under submarine conditions more rapid cooling must be conceded, resulting in the gouts of lava becoming immediately viscous on the outside through contact with cold water. One can imagine these small masses being expanded—literally blown out—by the pressure of the liquid lava still issuing from the crevice, and forming spheroids or the familiar pillows.

J. V. Lewis, in a very valuable paper, summarizes and criticizes the theories published up to 1914.[1] The variety and ingenuity expressed in these theories amply confirms Daly's statement that the formation of pillow structure is "a physical problem of fascinating difficulty". Lewis, who is not alone among American geologists in his opinion, although certainly in the minority, holds the unorthodox view that extrusion under or into water is not essential for the production of pillow-lavas. Photographs published in support of his view show pillow structure in recent basaltic flows at Kilauea. The upper surface only is available for inspection, and this is undoubtedly identical with the billowy upper surface of an ancient submarine pillow-lava flow. The suggestion is made that characteristic differences may exist between these rare sub-aerial pillow-lavas and the much commoner and better known submarine examples, but that these are not yet known. In attempting to account for the formation of pillow structure, this author elaborates a theory of "bulbous budding", the essential feature of which is the production of small multiple flows which form elongated or bulbous masses. Round these a tough membrane presumably of glass quickly forms on exposure to air or water. This membrane expands through the continued influx of liquid lava. The final stiffening of the crust of the bud is followed by cracking and the formation of another bud connected to the original one by a short neck. Contraction on cooling frequently results in the neck being severed, and the bud becomes the well-known isolated pillow with its own cooling surface and concentric internal structures resulting therefrom. The essential condition according to these theories is the rapid formation of the tough skin, stout enough to retain the liquid lava, but elastic enough to stretch considerably before final consolidation. It appears that the "budding" theory conforms to the observed facts, and has the advantage of not being dependent upon physical conditions which are but doubtfully possible. It will be noticed that in one respect the budding theory is in disagreement with the English views indicated above: according to the latter, a rolling movement is implied as being essential to the formation of the pillows, while no such movement is necessary in the former. Remembering

[1] Lewis, *Bull. Geol. Soc. America*, vol. xxv, 1914, p. 592.

that submarine slopes are usually very gentle, it is difficult to see how individual pillows could flow far over such a billowy surface as that possessed by a pillow-lava flow at any stage of its development. The Port Isaac-Padstow flow is estimated to cover an area of hundreds of square miles, and rests upon evenly bedded deep-water sediments which also cover it. There is no indication of a cone of the central type, and this may well have been a submarine fissure eruption. Now J. F. N. Green has pointed out that submarine lavas through the retention of magmatic vapours and gases will be of exceptional fluidity, thus being characterized by wide lateral extent. The great area of this particular flow is then not abnormal. Will the reader try to picture the lava spreading itself further and further from the fissure, using in turn the suggestions of Dewey and Greenly, and then those of Wilson and Lewis? In the first case we see spheres of molten lava formed in some unknown way, jacketted in steam, floating away from the fissure propelled by some unknown force (like myriads of gigantic *Volvox globator*) for, in some cases, a dozen miles from their source. In the second case we see the lava extending itself in much the same way as it does on land. On its surface the buds form, expand, freeze solid, often being broken off by the irregular onward movement of the flow, and occasionally rolling down the front or side of the flow—as isolated pillows. To accept the second explanation does much to destroy the sense of mystery which to the writer at any rate has surrounded the formation of pillow-lavas. It does sound possible, however, even probable, but it is so ordinary. In one other respect the English and American views are in opposition: the former correlate formation of pillows with a high degree of viscosity of the lava, while the latter deem extreme fluidity to be essential.

In view of the evidence brought forward by Lewis, one would be bold to deny the possibility of something akin to pillow structure being formed in a sub-aerial flow, but the geological record contains few, if any, definitely known examples of such. Britain has experienced many volcanic episodes, in the course of which basic lavas have been poured out in a variety of ways. Those definitely known to be submarine frequently show well-developed pillow structure, those poured into the waters of shallow lagoons show the same feature but rarely, while there is no case on record of a pillow-lava of proved sub-aerial origin. This can hardly be without significance, and the action of water as a controlling factor has been under-estimated by Lewis. It may be pointed out that the well-known and often quoted observations of Tempest Anderson at Matavanu proved lava of the pahoehoe type to assume pillow structure on flowing into water.

III. Varieties of Pillow Lava.

The pillow-lavas of this country are almost without exception spilites, and there is a tendency, therefore, to regard the two terms

as being synonymous. This is not the case. Basalts alluded to by Geikie as approximating to the picrite type occurring among the Carboniferous lavas of Fifeshire occasionally show pillow structure. From the Moro de Arica, Chile, Douglas has recorded typical pillow-lavas Mesozoic in age, bearing labradorite felspar, and termed by their discoverer "enstatite andesites"—typical calc-alkaline rocks in a calcic Province.[1] Even further removed from spilite is sudburite, the effusive equivalent of norite, containing bytownite, yet showing typical pillow structure at the type locality.[2] It is well known that during Pre-Cambrian times copious eruptions of lava, in the main of basic composition, took place over much of the Canadian Shield, especially in the Keewatin and, to a lesser extent, at higher horizons. In common with the Pre-Cambrian lavas of parts of Wales and Scotland, a magnificent development of pillow structure is characteristic of these flows, but on a much more extensive scale than in Britain.[3] Are these rocks spilites? The surveyors of the Canadian Shield still frequently refer to them by the descriptive but otherwise useless term "ellipsoidal greenstones", while to name them basalts, meta-basalts, andesites, or meta-andesites is of little use to the petrologist in the absence of careful identification and recording of the composition of the felspathic constituents of the rocks. Judging from the meagre petrographical details available, one cannot resist the conclusion that the American surveyor and the British worker among spilitic rocks are studying the same phenomena, possibly the same rocks. Some of these lavas would undoubtedly be regarded as spilites in this country, and they appear to be accompanied by keratophyres and quartz-keratophyres.[4] Others stated to contain andesine and "plagioclase, presumably labradorite", are evidently not spilites. Unfortunately, the relation of those which are, to those which are not, spilites is not made clear. This information would be of exceptional interest to many workers in this country. The aversion of American writers to using the names spilite and keratophyre is an added difficulty in the way of British readers of American geological publications, and agreement on this minor point of nomenclature is much to be desired.

The list of pillow-lavas which are not spilites might be considerably extended, but the examples given are sufficient to show that, although the structure is apparently identical in all cases, it is neither more nor less perfectly developed in spilites than in other kinds of basic lavas.

It is by no means invariably the case that spilites are pillowy throughout their entire extent: at Tayvallich, Llanwrtyd Wells,

[1] Douglas, *Quart. Journ. Geol. Soc.*, vol. lxx, 1914, p. 11.

[2] Iddings, *Problems of American Petrology*, 1915, p. 104.

[3] See for example Wilson, *Geol. Surv. Canada*, Mem. No. 39, 1914, and Alcock, Mem. 119, 1920, p. 17.

[4] Cooke, *Geol. Surv. Canada*, Mem. 115, 1919, p. 11.

and at numerous other localities, pillows occur in the upper part of the flows only. Elsewhere they are restricted to the lower portion, while more rarely the flows are entirely massive (non-pillowy). Contrasting strongly with these are the magnificent exposures at Pentire, North Cornwall, and Chipley, South Devon, in the former case well-formed pillows being piled one upon another to a thickness of over 200 feet. Evidently pillow structure is neither restricted to nor invariably developed by spilites, although extremely characteristic of them. It is, however, a flow phenomenon produced in submarine lavas of varying composition, and depending for its formation upon suitable conditions of temperature, viscosity, and possibly rate of extrusion.

IV. Intrusive Spilites.

Much difficulty has been experienced in proving spilites to be definitely extrusive or definitely intrusive in almost all localities where they occur. Most occurrences now known to be true flows were formerly regarded as intrusions, while those for which an intrusive origin has lately been claimed were formerly accepted without question as being extrusives. For example, after detailed study of the contacts of the Devonian pillow-lavas (spilites) of the Nundle District of New South Wales, Benson has concluded that most, if not all, of these, formerly thought by him to be flows, are in reality shallow intrusions.[1] Similarly, Lawson regards all the variolitic spheroidal basalts and diabases of the San Francisco Bay area, claimed to be the most typical pillow-lavas to be found anywhere, as intrusive rocks. The lavas of the Loch Awe Group were regarded as sills until 1911, when Peach's field evidence indisputably established them as true flows.[2] The occurrence of pillow structure has been looked upon in the past as a sure indication, one might even say proof, of the extrusive nature of the rock concerned. But these few exceptions indicate that the proof must not be accepted blindly, without careful examination of the junctions. To the general acceptance of this principle there is at least one dissentient whose beliefs must be recorded as a definite statement of opinion founded upon detailed field observations. Worth believes that the pillow-lavas of Devonshire are intrusive; that the part of the magma chilled against the country rock was rendered viscous and rolled and kneaded against the walls of the "dyke" by the advancing magma. He interprets the (apparently) isolated pillows as the ends of lobe-like off-shoots from the main intrusions, viewed in section.[3]

To account for the transgressive boundaries of the Nundle spilites Benson uses an explanation which has proved useful in a number of cases since first suggested in 1911, viz. that the rocks represent bodies of magma intruded into unconsolidated submarine ooze.[4]

[1] Benson, *Proc. Linn. Soc. N.S. Wales*, pt. i, 1915, p. 121.
[2] Bailey, *Quart. Journ. Geol. Soc.*, vol. lxix, 1913, p. 282.
[3] Worth, *Trans. Devon Assoc.*, vol. xlviii, 1916, pp. 217–59.
[4] Teall, *Mem. Geol. Surv.*, Knapdale, 1911, p. 84.

The writer believes this principle to be of more general application than is at present accepted, and to be the true explanation of all those cases where difficulty is experienced in interpreting the field evidence. The soft ooze of the sea floor, which is often incapable of supporting the weight of a crustacean unless raised aloft on stilts, would certainly not be able to support the weight of pillows of lava eight feet in diameter. It is more than a possibility that on striking a soft patch the flow would extend itself through the ooze instead of along its surface. Under such conditions transgressive boundaries would be the rule rather than the exception, and it seems more difficult to explain conformity between the base of a flow extruded into really deep water and the underlying sediment than the transgression. It is possible that most of those pillow-lavas which contain much sediment, black shale, or limestone, in the interspaces are of this order. The material between the pillows, although in some cases deposited later, as shown by horizontal bedding planes,[1] has without much doubt been frequently forced into position by the sinking of the pillows. As a point of historical interest the theory of Platania and Johnston-Lavis may be mentioned.[2] They regarded injection of magma into a thick stratum of submarine sediment as the prime cause of pillow structure. Although widely accepted at the time, the theory is, of course, out of date, and the acceptance of the explanation of Dewey and Flett precluded the possibility of an intrusion even of this abnormal kind developing pillow structure. The conditions are reversed, however, if the budding hypothesis is accepted: budding would probably proceed almost as readily in watery ooze as in pure sea water.

Various writers have pointed out that under deep water conditions the distinction between sill and flow practically disappears. Thus Harker states that "some (sills) are forced in among sediments actually in the process of formation in deep water. . . . Here belong many of the rocks distinguished by what Sir A. Geikie has styled pillow structure".[3] Whether these bodies (shallow intrusions) should be called intrusions at all, is open to question: in all essentials these rocks are lavas. The slight increase in external pressure was not sufficient to inhibit the production of the abundant vesicles so common in spilites, neither was the blanketing action of the mud sufficient to prevent rapid cooling, so that the internal structures are those of true flows. The difference between these hybrid examples and the true sills is that the latter penetrate strata horizontally, because they are unable to progress further vertically owing to the strength of the overlying "roof", while the former penetrate loose sediments, generally in a sill-like manner, because these are "incompetent to support the weight of the flow".

[1] Geikie, *Mem. Geol. Surv.*, Central and West Fife, 1910, p. 54.
[2] Platania and Johnston-Lavis, *The S. Italian Volcanoes*, 1891, pp. 37–44.
[3] Harker, *Natural History of Igneous Rocks*, 1909, p. 64.

Reference may here be made to an important paper by J. F. N. Green in which the features which characterize the submarine lavas of the Lake District are detailed.[1]

Pillow structure is not stated to be a necessary attribute of submarine flows, which he considers should be of wide lateral extent, but of no great thickness, and showing uniform vesicularity and frequent autobrecciation. Is one to suppose these features to be independent of chemical composition, or do they characterize lava of a particular type? As we have seen, pillow structure is developed in the very fluid basic lavas, and is analogous to pahoehoe structure on land. May it not be that autobrecciation is produced in more viscous lavas of andesitic composition, and is the analogue of "aa" structure on land?

V. Chemical and Mineral Composition.

No great advance in our knowledge of the mineral composition of spilites can be recorded, as but few additional analyses have been made in the last ten years. Before our knowledge of these rocks can approach completeness, many more analyses must be prepared, as the number available is totally inadequate to supply data for a bulk comparison of the spilitic with other types of magma. The average of seven analyses is recorded below, these being the analyses of typical spilites from Devonport and Chipley (Devon), New Cumnock, Tayvallich, and Mid-Argyll (Scotland), Newborough (Anglesey), and Nundle (N.S.W.). Analyses of the average basalt, average nepheline-basalt, and average nepheline-basanite are quoted (from Daly) for purposes of comparison.

	Basalt.	*Neph. Basalt.*	*Neph. Basanite.*	*Average Spilite.*
SiO_2	49·06	39·87	44·41	46·01
TiO_2	1·36	1·50	1·56	2·21
Al_2O_3	15·70	13·58	15·81	15·21
Fe_2O_3	5·38	6·71	4·66	1·35
FeO	6·37	6·43	5·85	8·69
MnO	0·31	0·21	0·14	0·33
MgO	6·17	10·46	8·20	4·18
CaO	8·95	12·36	10·12	8·64
Na_2O	3·11	3·85	3·81	4·97
K_2O	1·52	1·87	2·37	0·34
H_2O (+)	1·62	2·22	2·42	2·48
P_2O_5	0·45	0·94	0·65	0·61
CO_2	—	—	—	4·98

It will be noted that while the percentages of silica, alumina, total iron oxides, and total alkalies are comparable in all four averages, the average spilite is distinctive in the following particulars: very high percentage of TiO_2, soda and carbon-dioxide; very low percentage of magnesia and potash; state of oxidation of the iron. The suggestion has been made, and is widely accepted, that the spilitic rocks are intermediate in character between the calcic and alkaline

[1] Green, *Proc. Geol. Assoc.*, vol. 30, 1919, p. 153.

suites, i.e. that they represent magma which has travelled a certain distance, but not far, towards the alkali pole. This is not borne out by the chemical analyses of the rocks. In no sense is average spilite intermediate between average basalt and the average felspathoid lava, but is distinct from both. This individuality can be explained only by imagining special formational processes.

The small number of spilites analysed is accounted for by the altered state of the rocks, only one of the seven averaged being what one might correctly term " fresh ". This is partly accounted for by the age of the rocks, none being younger than Devonian, in part because they have been involved in intense earth movements, but principally on account of metasomatic changes which affected the rocks during or immediately after consolidation. This alteration is indicated in the analyses by the high percentages of combined water and carbon-dioxide usually present, the latter ranging up to 10 per cent, sufficient to account for all the available lime, thus leaving none for the formation of the anorthite molecule. Thus the place of the characteristic labradorite of normal basalts is taken by albite or albite-oligoclase, this peculiarity being the chief diagnostic characteristic of spilites, which distinguishes them from all other lavas of like basicity. The question of whether the albite of spilites is primary or secondary remains, in many instances, an open question. Granted the original richness in soda which the composition of the rocks demands, there is no inherent reason why the albite should not be primary; in fact, the easiest way to get it into its present position is to suppose that it crystallized as such from the magma. In some instances this has certainly been the case. Benson fails to find any evidence that the acid plagioclase in the Nundle spilites is other than primary.[1] Many published descriptions of spilites contain no discussion of the question, presumably from lack of evidence or difficulty in interpreting what is seen. Flett, when describing the spilites of the Newton Abbot district, suggests that a certain amount of primary albite has been increased by the albitization of an originally more basic plagioclase, the whole of the felspar being now almost pure albite.[2]

To invoke albitization, which has undoubtedly modified the coarse-grained, intrusive, albite-dolerites in this way, implies that, although the requisite amount of soda to form albite was present in the magma, it did not render the plagioclase as sodic as possible, but a portion remained unattached as a component of the residual liquors. These, after extrusion of the magma but prior to final consolidation, leached out the lime from the plagioclase, replacing the latter with soda, the resultant lime crystallizing in the vesicles as calcite. This change is the result of the magma " stewing in a solution of sodium carbonate ", and has been termed auto-metamorphism or autolysis,

[1] Benson, op. cit., p. 140.
[2] Flett, *Mem. Geol. Surv.*, Newton Abbot, 1910, p. 61.

the necessary condition being the rapid formation of an impervious skin completely imprisoning the residual liquids.

The altered condition of spilitic rocks has been frequently commented upon, but the author is of the opinion that this is a mistaken view, for, if the above theory is correct, the analysis of a spilite more closely represents the actual composition of the magma than most analyses of lavas extruded under sub-aerial conditions, and from which much volatile material escapes during the final stages of consolidation. The striking similarity between albitization and analcitization has often been a matter of comment. A strong case has been made, and has been widely accepted, for regarding the analcite in teschenites and allied rocks as a primary constituent of these rocks. The "secondary" albite of the spilitic rocks has played a similar rôle and occupies a similar position. Having been formed prior to the final consolidation of the rock, it also should be regarded as a primary mineral. The small proportion of potash present is noteworthy, and is not in excess of that found in average albite. Orthoclase cannot, therefore, be regarded as an essential mineral of these rocks. Concerning the original coloured constituents of spilites, little can be said, as in the majority of cases they have been completely replaced by chloritic and serpentinous minerals, which, being soft and easily deformed, rarely yield definite evidence of the minerals they have pseudomorphed. In all cases where an original coloured mineral does remain, it is a brownish coloured augite, usually granular, but occasionally sub-ophitically related to the abundant felspar. Alteration to chlorite (not to hornblende) is generally complete. The presence or absence of olivine remains doubtful in most cases, although occasionally its presence has been discovered by careful search, e.g. in the Newborough (Anglesey) rock.

VI. Petrogenesis.

The Spilitic suite receives but little respect from the majority of American writers who have published their opinions on the subject. Daly regards them as being pneumatolytic derivatives of normal basaltic magma. To him the "so-called spilites" are but "an illustration of the bond between the alkaline and calcic suites".[1] Bowen's papers on the origin of the alkaline rocks contain no discussion of the spilites. Lewis, although recognizing the peculiarities of the rocks, briefly dismisses them as "altered basalts".[2]

Nobody denies that the abundant soda in spilites is derived from the magma, but the mechanism whereby this richness was produced has long been a matter of dispute. It is agreed also that differentiation of some kind has produced this high degree of alkalinity from some larger body of more normal, probably basaltic, magma.[3] Disagreement concerning the exact process whereby a particular

[1] Daly, "Genesis of the Alkaline Rocks": *Journ. of Geol.*, 1918, p. 101.
[2] Lewis, op. cit., p. 535.
[3] Daly, *Igneous Rocks and their Origin*, 1914, p. 339.

rock type has been produced is no excuse for denying the identity of the rock, or for belittling its importance. To maintain that spilite is an altered basalt is likewise begging the question: one does not describe the "pouter" as an altered rock pigeon! Basalt and spilite have very possibly been derived from a common stock. The actual mechanism which has separated the potentially spilitic portion from that which elsewhere, and in other circumstances, has resulted in flows of normal basalt is differently conceived by various writers. But whether earth movements of a particular kind, or eruption under submarine conditions, or assimilation on any reasonable scale be the theory favoured, the fact remains that the modification of the parent magma has been, at certain periods, very profound and of wide regional extent.

It is important fully to realize that the question is not confined to the origin of an isolated rock, but of a series, varying in composition from ultra-acid to very basic, and exhibiting all of the textural variations common to the calcic and alkaline suites. This indicates that magma drawn from all levels in the reservoir was similarly modified. If this were not the case, and if the spilitic magma could be pictured as an alkaline scum lying in the reservoir above a much more bulky basaltic portion, the latter would either precede or follow extrusion of the former, and intimate association of the two rocks, basalt and spilite, would result. The British geological record does not appear to furnish an example of this reversion of spilitic to calcic rocks or vice versa. At the same time, the theory favoured in this country that spilitic rocks are the result of "long-continued subsidence with few or slight upward movements and no important faulting" is an evolutionary process demanding time for its fulfilment. The evolution may be complete, or conditions may arise which check it at an early stage, resulting in the formation of intermediate rock types or of a limited amount of spilitic magma. The basic lavas of Lower Carboniferous age in Derbyshire have been stated to include such intermediate types, intermediate in geographical position as well as in composition between the basic lavas of Scotland and those of S.W. England. The dominant rocks are normal, fresh olivine-basalts and dolerites, with which are associated, however, an abnormal rock type rich in alkalies. To these alkaline rocks the name "potash spilite" has been applied. Now Holmes defines *mugearite* as being "distinguished from basalt by the occurrence of oligoclase and orthoclase in place of labradorite, by containing olivine in greater amount than augite, and by the possession of a trachytic rather than a basaltic texture". The so-called spilites of Derbyshire are basic lavas containing phenocrysts of andesine or acid labradorite, set in a trachytic ground-mass of oligoclase, a small amount of andesine, together with a large proportion of orthoclase. Both olivine and augite occur, the former being sometimes in excess. These rocks occur as individual flows and as the lower parts of flows of normal olivine-basalt. Mugearites

occur in the Midland Valley of Scotland intimately associated with basalts of the Markle type, but an interbedding of basalt with spilite has not yet been reported in this country. Obviously, then, in mineral contents, texture, and mode of occurrence, these rocks are much nearer to mugearite than to spilite, and the use of the latter name is unfortunate and misleading. Bailey has remarked upon the similarity of the rocks under discussion to the albitized basalts of the Midland Valley of Scotland, but it should be noticed that in the former case the modifying fluids were rich in potash rather than in soda, the secondary felspar being orthoclase, not albite.

The Derbyshire lavas shed interesting light on the petrogenesis of spilite-like rocks. Among other agents which have been suggested to account for the formation of the latter, the following may be mentioned :—

(1) The action of resurgent water.

(2) The pressure of the water-column above the flow, causing retention of the volatile constituents and supplying a medium through which these could act.

(3) The chemical action of sea water highly heated by contact with the lava and charged with magmatic gases.

(4) The joint action of magmatic and meteoric waters.

(5) Self-digestion of the lava, caused by retention of magmatic solutions in a retentive envelope of rapidly chilled rock.

Now the special conditions of temperature, pressure, and gaseous content suitable for the production of pillow structure have been reproduced again and again, from early Pre-Cambrian to Upper Eocene times, in lavas of andesitic to basaltic composition. The physical conditions of these flows must have been similar within very narrow limits, but the rock has by no means invariably been spilite.

Now it will be noted that the normal basalt, as well as the peculiar mugearitic rocks of Derbyshire, were extruded from the same vent at almost the same time ; that both were, therefore, extruded under the same physical conditions; that both were alike exposed to the modifying influences arising from the circumstance of submarine eruption. The outer part of the basalt, as well as the mugearite, would be suddenly chilled, and their cooling history would be alike. In spite of these facts, the basalt has remained basalt, quite indistinguishable from that erupted under other conditions, while the more alkaline rock exhibits modifications comparable with those seen in true spilites. This proves that the modifying action of sea water on rock magmas is practically without effect. Again, that it cannot be only a question of pressure causing retention of gases is apparent, otherwise normal dolerites forced into cool rock and, therefore, enclosed in an envelope of chilled material, should approximate to the spilite type, and the close association of normal basalt flows with spilite intrusions would be a common phenomenon.

Physical conditions alone are not adequate to account for the chemical and mineralogical peculiarities of spilites. One must

postulate, in addition, a magma which, before extrusion, was differen from the normal basaltic, possessing a marked richness in soda an deficiency in magnesia when compared with the latter.

The writer knows of no official definition of a rock suite, but if th term implies a series of rocks genetically connected by derivatio from a common stock possessing similar chemical and mineralogica characteristics, thus bearing the stamp of heredity, then the range o lavas comprising the quartz-keratophyres, the intermediate kerato phyres, and the basic spilites, together with their intrusiv equivalents, constitute a well-marked suite.

Some Non-foliated Igneous Rocks in Tanganyik Territory, and their bearing on Tectonic Problem in that region.

By E. O. Teale, D.Sc., F.G.S.

CALCIC and alkaline eruptive rocks representing many varietie have an extensive development along the northern portion o the eastern Rift Zone in the Tanganyika Territory. They ar closely similar to those better known to British geologists in Keny Colony, and in both areas have received a considerable amount o attention from petrologists.[1] In Tanganyika Territory the neares of these occurrences to the Indian Ocean hitherto known, with on exception, to be referred to later, is more than 130 miles from th coast, and the greatest development lies at 170 to about 250 mile inland.

The coastal zone, composed very largely of sediments, rangin from Lower Karroo through marine Jurassic and Cretaceou beds, is remarkably free from igneous rocks of any kind, thu contrasting strongly with many other coastal regions in Easter Africa. There are not wanting, however, other features in th form of faults, fracture zones, and hot springs which indicate dislo cations to be correlated with the tectonic history of Eastern Afric from post-Karroo to recent times.

The only previous record of eruptive rocks within the coastal bel is due to Bornhardt,[2] who described the occurrence of dykes o olivine-basalt, andesite, and phonolite with a bearing of 140 degree on the north-west side of the Luhembero, an isolated hill of Karro rocks rising out of the low plains to the south of the Rufiji River and distant from the coast in a straight line about 80 miles.

In Kenya Colony at Mt. Jombo, about 20 miles inland, Gregory describes nepheline-syenite and ijolite with associated dykes o

[1] For a comprehensive bibliography see J. W. Gregory, *Rift Valleys an Geology of East Africa*, 1921.

[2] W. Bornhardt, "Zur Oberflächengestaltung und Geologie Deutsc Ostafrikas": *Deutsch Ostafrika*, vii, 1900.

[3] Op. cit., pp. 191, 192.

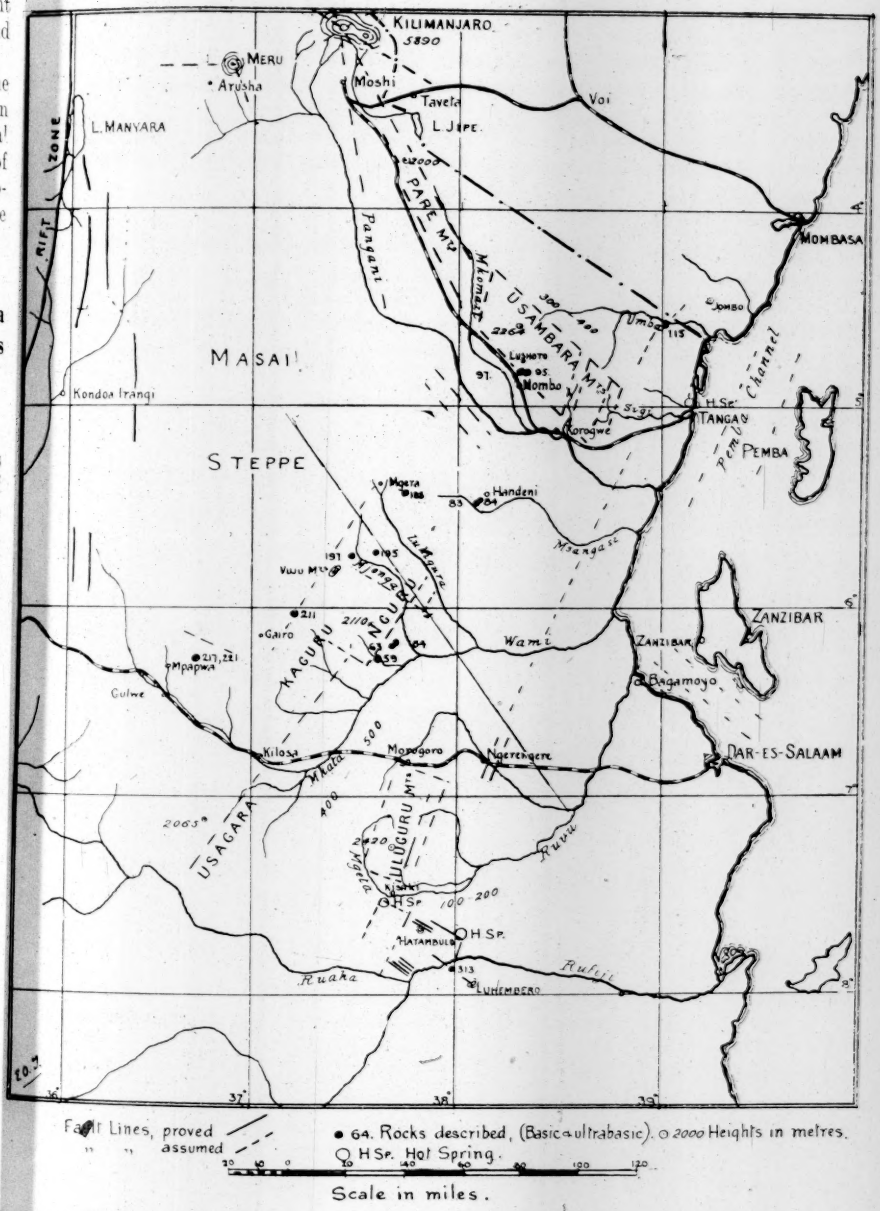

FIG. 1.—Portion of Tanganyika Territory. Tectonic map, showing also position of rocks described.

camptonite. These intrusions are correlated with the volcanic events which built up Kilimanjaro and Kenya.

The present contribution records the occurrence of some igneous rocks, mainly basic and ultrabasic types, from some hitherto unrecorded localities, and apart from interesting features exhibited by some of these specimens, a study of their distribution suggests some further observations on the tectonic history of a region well to the east of the Rift Zone.

Four distinct regions are referred to :—

1. The Umba district, close to the frontier in the north-east portion of the Territory, at about 18 miles inland.

2. The West Usambara Highlands, at about 60 miles inland in a straight line.

3. The Kaguru and Nguru Highlands, at 70 to well over 100 miles inland.

4. The Rufiji Valley, at about 90 miles inland.

1. The Umba District.

The specimen from this district (No. 115) represents a biotite-hornblende-augitite, and though it was a loose piece picked up on a native pathway, it did not have the appearance of having travelled far, and it was certainly not a native implement. The locality lies about 18 miles north-west of Moa, within the sedimentary area of the ? Permo-Triassic beds of the Tanga hinterland, close to its western boundary with the crystalline rocks, which, in this vicinity, consist of massive beds of crystalline limestone associated with gneiss. Though no dykes were found, it is not improbable that they exist in the neighbourhood,[1] and it is, perhaps, significant that the production of a N.N.E. line from this area—a dominant tectonic direction in the region—would pass close to the Jombo Hill in Kenya Colony, previously referred to, and about 15 miles distant.

The rock is dense, dark and aphanitic, except for scattered lath-shaped phenocrysts of augite up to 5 mm. long, with occasional long flakes of black mica. The thin section shows abundant good prismatic phenocrysts of faintly green augite, and there is one instance in the slide of green ægirine-augite as a kernel in the normal augite. Hornblende of clear, yellowish-brown colour occurs in irregular, corroded plates up to 2 mm. in greatest length and in several long, prismatic laths showing twinning. Pleochroism is marked, ranging from light brownish-yellow to deep reddish-brown. The extinction angle of all sections observable is low, in general from 7 to 8 degrees. It is probably, therefore, barkevikite. Small scattered plates of deep red-brown biotite are present. The above minerals are set in a cloudy base with numerous small pyroxene prisms. Occasional patches of clear isotropic substance, partly cloudy by decomposition, may be analcite. Magnetite is very

[1] Mr. C. W. Hobley informs me that he noted a dark dyke in Kenya Colony not many miles from the frontier in the same region.

abundant. The Sp. Gr. is 2·8. The above rock differs somewhat from the augitites described by Miss A. T. Nielson [1] from Kenya Colony in the presence of biotite and hornblende, and the rarity of ægirine-augite, while the existence of nepheline has not been established. It appears to be closest to those described from the Lake Magadi region, but more probably represents a more basic phase of the camptonite dykes of Mt. Jombo.

2. The West Usambara Highlands.

The Usambara Highlands form one of the most attractive regions in the Territory. Uhlig,[2] following Hans Meyer,[3] refers to the district as a gneissic horst bounded by faults and traversed by cross fractures. This view is based on physiographic features, and my own observations strongly support this hypothesis. In general, the region consists of gneiss in part of normal character, but pyroxenic, hornblendic, and garnetiferous types are abundant. Little, however, is known of the detailed geology and petrology of the area. Non-foliated rocks appear to be rare, and apart from the pegmatites in the western and north-western portion which have been worked for mica, only one record of non-foliated igneous rock is known to me. P. Range [4] refers to granitic laccoliths intruding the gneiss close to the steep western edge of West Usambara, about 6 miles north of Mombo, in an area also intersected by pegmatites once worked for mica. No petrological description is given of the rock, and in a hurried visit to this area during the rainy season I was unable to observe the laccolithic intrusion, but two types of enstatite- and hypersthene-bearing rock, probably closely connected genetically, were noted. The least basic of these rocks (No. 97) is a rather felspathic norite which occurs in thin reticulating veins intruding the normal gneiss on a steep ridge about three-quarters of a mile east of the house built in connexion with the now abandoned Madala Mica Mines. The rock has medium-grained granitic texture, is light greyish green in colour, speckled with dark ferro-magnesian minerals tending to prismatic in outline. There is no sign of foliation either in the hand specimen or in the thin section. Felspar makes up about two-thirds of the rock. Albite twinning is well developed, and occasionally that of the pericline type. Extinction angles on suitably orientated sections indicate an andesine approaching labradorite. There is no quartz. Enstatite and hypersthene are the dominant mafic minerals; they occur in large, irregular plates up to 3 mm. in greatest length. The hypersthene shows pleochroism from faint green to pinkish brown and polarization colours higher than the enstatite. The enstatite has a small amount of greenish brown hornblende in minute parallel intergrowth, and both pyroxenes

[1] Gregory, op. cit., p. 403.
[2] C. Uhlig, *Deutsch-Kol. Lexikon*, 1920, p. 589.
[3] Hans Meyer, *Der Kilimanjaro*, 1900, pp. 15, 24, 42.
[4] P. Range, *Zeitsch d. Deutsch Geol. Ges.* 64, 1912, p. 372.

have a similar hornblende as an irregular marginal growth. Iron minerals are unimportant, and there is only a little apatite. The Sp. Gr. is 2·92.

Specimen No. 98 is from the same locality, but a little lower down the slope in a westerly direction, and represents a pyritic pyroxenite. It is a coarse-grained, dark bronzy-brown rock consisting almost entirely of pyroxene, chiefly hypersthene. There is a subordinate amount of greenish brown hornblende occurring as marginal grains round the pyroxenes, and the pyrite has a similar relationship. The hypersthene occurs in large plates up to about 6 mm. in greatest length, showing good schiller effects and pleochroism from a salmon pink to a light green.

Hypersthene-bearing rocks have been previously recorded from several localities in this part of Africa. A hornblende-hypersthene-peridotite was described by Dr. Hatch[1] from Losilwa Hill, Taveta. An olivine-hypersthenite was collected by von der Decken from between Taveta and Lake Jipe, and described by Dr. Rose.[2] Along the western side of the Pare Mountains there are two records of amphibole-hypersthene-granulite, due to Rosiwal,[3] and the same writer describes hypersthene-plagioclase-gneiss from two localities at the western foot of the Usambara Mountains near Korogwe. The charnockite series, therefore, as indicated by Gregory,[4] would appear to have a wide distribution in this part of Africa.

3. The Kaguru and Nguru Highlands.

This mountain region forms a broken and dissected block of gneissic rocks, many points of which rise to elevations of 4,000 to 5,000 feet above sea-level, and several reach well over 6,000 feet. It is continuous southerly with the Usagara Highlands, and together these mountains represent the eastern margin of the Central Highlands and plateaux of the territory. The eastern boundary is sharply marked off for nearly 100 miles along the western edge of the Mkata and Wami plains by a striking though dissected scarp rising steeply from 1,500 to over 2,000 feet above the plain, which is here from 1,450 to 1,500 feet above sea-level. The straight character and trend, in general about N.N.E. but in detail somewhat zigzag, of this feature are noteworthy, since its direction is parallel with one of the dominant tectonic lines of the Territory. Dantz [5] regarded this marked change in the topography as a fault line apparently based on physiographic considerations; and W. Koert,[6] in reviewing the tectonic features of the country at a much later date, though not

[1] F. H. Hatch, Geol. Mag., 1888, p. 257.
[2] G. Rose, *Zeit. Allg. Erdkunde*, Berlin, N.S., xiv, xv, 1863.
[3] A. Rosiwal, *Denk. Akad. Wiss. Wien*, lviii, 1891, pp. 465–550.
[4] J. W. Gregory, op. cit., p. 31.
[5] A. Dantz, Die Reisen des Bergassessors Dr. Dantz in Deutsch Ostafrika in den Jahren, 1898, 1899, 1900. *Mitt. d. D. Schutzgeb.*, 1902, 1903.
[6] W. Koert, *Beiträge zur geologischen Erforschung der Deutschen Schutzgebiete*, Heft 1, 1913, p. 231.

accepting some of the conclusions of Dantz regarding fault scarps elsewhere, strongly favoured his view in this case. My own traverses followed the eastern base of this region from Kilosa northwards, and also covered some new ground along a somewhat parallel line further west, and it would appear significant that in both instances, at intervals, basic and ultra-basic intrusions were observed which are almost certainly to be correlated with some period of the great Rift Zone disturbances of Eastern Africa, and in several places also along the eastern traverse, brecciated rock much silicified by hydro-thermal action was collected. This is a common feature along many fault lines in the territory. The detailed tectonic history of this area is complex, but it would appear certain that at one period, probably the early part of the Rift Zone history, it suffered considerable fracturing and dislocation.

Petrology of the Rocks.

No. 59. This specimen belongs to the peridotite family, but is noteworthy for the variety of mafic minerals it contains, comprising olivine, monoclinic and rhombic pyroxenes, biotite, and brown hornblende. Large loose boulders of it occur at the Mkindu Falls, and, since this is one of the shorter of the eastern streams of the Nguru Mountains, it is fairly safe to conclude that it belongs to the eastern slope of the highlands. It is a dark, somewhat fine-grained crystalline rock of doleritic appearance, but showing under the lens a considerable amount of brown, bronzy-yellowish, and greenish minerals, interspersed with others which are black. Small brownish-black scales of mica are recognizable.

There is no sign of foliation, but the somewhat granular character suggests a certain amount of granulation and recrystallization, probably late-magmatic. The thin section shows large clear areas of irregular outline, consisting of olivine and pyroxene, usually much cracked with a certain amount of disruption. The intervening space is composed of yellow to yellow-brown coloured minerals, partly in irregular plates, but a considerable amount also is granular. The coloured and clear minerals are almost equal in amount, and the former consist of yellow to red-brown biotite, and yellow to yellow-brown hornblende, with an extinction varying from about 9 to 13 degrees. Some of the yellow granular mineral is probably epidote. Iron minerals are present, but not abundant.

The pyroxene is in part monoclinic, in part rhombic, the latter being chiefly enstatite with characteristic low polarization colours and straight extinction. Occasionally, it has a somewhat pleochroic core representing more ferruginous composition, probably bronzite. Reaction rims are not typically developed, but there is a tendency to marginal arrangement of the biotite and hornblende round the corroded edges of some of the large pyroxenes and olivines indicating secondary reactions. The changes are regarded as late-magmatic rather than subsequent dynamo-metamorphic. The Sp. Gr. is 3·3.

No. 63. This specimen comes from 6½ miles to the north-east, or about 3½ miles south-west from Turiani at the foot of the scarp. There are numerous loose pieces on the track, and it is clearly in situ close at hand. It is a peridotite related to No. 59, but is partly serpentinized. It probably contained, originally, more olivine and less pyroxene than the first rock, and there is no trace of the granular interstitial structure shown in that specimen. Brown hornblende, reddish-brown hypersthene, and deep red-brown biotite are recognizable.

No. 64. This specimen was collected from a position about three-quarters of a mile further on towards Turiani, and more closely resembles in structure again No. 59. It is a little finer in grain and shows no serpentinization, but has the same patchy appearance in ordinary transmitted light, due to clear pyroxene and olivine with interspersed yellow and yellow-brown minerals consisting of biotite, hornblende, and (?) epidote. The pyroxene is largely enstatite with occasional pleochroic centres of bronzite or hypersthene.

No. 83. This rock occurs in situ as an irregular intrusion of undetermined extent in an area consisting mainly of hornblendic and graphitic gneisses with interbedded crystalline limestone, and is situated 8·4 miles south-west from Handeni. It is a mica-hornblende-pyroxene-peridotite with green spinel. This is a somewhat coarser-grained rock approaching the gabbro texture. It has a general dark brown colour, and contains a little pyrite as disseminated grains. The thin section shows the typical yellow to yellow-brown and red-brown colour of the coloured minerals which include pyroxene, hornblende, and a subordinate amount of deep red-brown mica. Large colourless olivines tending to idiomorphic outline are abundant. They frequently have a well-defined reaction rim of enstatite and partly of monoclinic pyroxene. The olivine is also, at times, completely enclosed in light-brown, non-pleochroic platy pyroxene, or in deeper yellow-brown pleochroic hornblende. The central portion of some of the hornblende is sometimes black, with inclusions of iron minerals. A little pinkish to violet hypersthene is present. Spinel is moderately abundant as deep green crystals enclosed in the hornblende or pyroxene. Good octahedral outlines are frequently recognizable. The rock is fresh, save for a few small decomposition areas, some of which show a little incipient serpentinization. The Sp. Gr. is 3·33.

No. 84. This rock occurs 2 miles to the north-north-east of No. 83, which it very closely resembles, but it is finer in grain, and shows no spinel in the slide. There appears to be a little more hypersthene and a greater amount of cloudiness due to decomposition.

The next rocks to be described lie along a somewhat parallel line some 30 to 40 miles further west, approaching the borders of the south-east portion of the Masai Steppe.

The most northerly of these occurrences, No. 188, lies along the route from Handeni across the Masai Steppe to Kondoa Irangi, and

at about 30 miles west in a straight line from Handeni. It forms a low hill rising about 200 feet above the surrounding gneiss country. It is a dark, crystalline rock of gabbroid appearance showing dark bronze-coloured and light green mafic minerals with occasional scales of dark mica.

The rock is related to the peridotites just described, but is less basic, containing a certain amount of felspar, which is, however, subordinate to the mafic minerals, and in addition garnet is present. The yellow to red-brown minerals are much less abundant, being only represented by biotite and a little epidote. No hornblende has been recognized, but hypersthene with patchy, pinkish to violet tint is more abundant. Pyroxenes preponderate over olivine, and reaction rims are a striking feature. The rock may best be described as a norite approaching the ultrabasic group in composition.

The felspar, which is subordinate to the mafic minerals, shows well-defined lamellar twinning according to the albite law, and suitable sections give extinction from 30 to 45 degrees indicating anorthite. It is strikingly cloudy with minute inclusions consisting of prisms of higher refractive index than the felspar.

The reaction rims, which are such a noteworthy feature of this rock, deserve some notice. The olivine shows a distinct rim of enstatite followed by an outer zone of granular garnet and a little interstitial monoclinic pyroxene. In another instance there is a centre of granular pyroxene surrounded by granular garnet, and the whole enclosed in a poikilitic manner by plagioclase. The original pyroxenes invariably show some reaction round the margin, usually in the form of a discontinuous and narrow fringe of clear, or occasionally faint green granular pyroxene, and sometimes garnet. Another type consists of a granular aggregate of monoclinic and rhombic pyroxene (which has apparently entirely replaced olivine), surrounded by a more or less continuous rim of garnet. The brown mica tends also, but in an imperfect manner, to wrap round some of the pyroxenes. It is also found in peculiar micrographic intergrowth with pyroxene. All these features appear to be strongly indicative of progressively changing magmatic conditions during the crystallization of the rock rather than later metamorphic conditions. The Sp. Gr. is 3·2. (See Fig. 2.)

No. 195. This is another ultrabasic intrusion consisting of a mica-hornblende-pyroxene-peridotite, closely similar to the previously described rocks of this type. It resembles No. 84 in the proportion of yellowish and yellow-brown minerals and red-brown biotite. There is more pyroxene than in No. 64. Reaction rims of enstatite round olivine are noticeable. The hornblende is the yellow-brown variety with strong pleochroism from pale yellow to deeper yellowish-brown with low extinction angle. Iron minerals are not abundant.

This intrusion occurs in hornblende-biotite-gneiss at the base of Lekoleko Hill, 1 mile south of the village of Vihingo.

No. 197. This rock represents another occurrence of exactly similar type to No. 195, but is finer in grain. It occurs between Vadigwa and Kwakivu villages, about 9 miles W.S.W. from No. 195.

No. 217. This rock occurs as a group of small knolls in the floor of the Tubugwe valley, close to the village of the same name. It is a dark, basaltic-looking rock with a certain amount of sheen due to the schiller of the rhombic pyroxenes. It is related to the ultrabasic group just described. The presence of a certain amount of felspar would place it with the basalts, but structurally it is akin to the

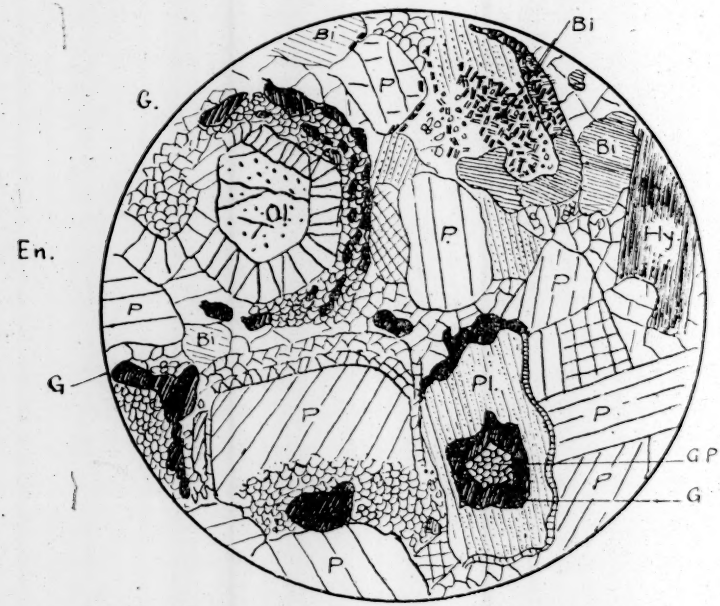

FIG. 2.—No. 188. Norite, approaching the ultrabasic group in composition, from 30 miles west of Handeni. This rock is noteworthy for reaction rims. Ol. Olivine with reaction rim of enstatite (En.), followed by an outer zone of granular pyroxene (G.P.). Bi. Biotite, either in irregular plates or micrographic aggregates. Pl. Plagioclase, anorthite, cloudy with numerous inclusions and with a border in part of garnet, elsewhere consisting of a thin fringe of faint green pyroxene. Enclosed within the felspar is an aggregate of granular pyroxene surrounded by garnet. Hy. Hypersthene.

NOTE.—This diagram is a representation drawn from four separate portions of the thin section.

more basic division. The granular interstitial minerals, the enstatite, yellow-brown mica, and tendency to reaction rims are features which recall the previous rocks. This specimen may be called a mica-enstatite-basalt approaching an augitite in composition. Two other slides from the same locality indicate that the rock is variable in the proportion of its minerals and in details of structure.

The thin section of the first specimen, No. 217, is noteworthy for the strikingly zoned pyroxene phenocrysts from 0·5 millimetres to about 0·75 mm. in greatest length. These occur singly or in twinned groups, and show, in ordinary transmitted light, a blue-black to violet-brown dusty appearance, non-pleochroic in polarized light. It is probably due to finely-divided ilmenite. There is abundant yellow-brown biotite of irregular outline, often containing a ragged, central patch or cluster of grains of iron minerals, and, in addition, numerous granular inclusions of pyroxene. There are also granular aggregates

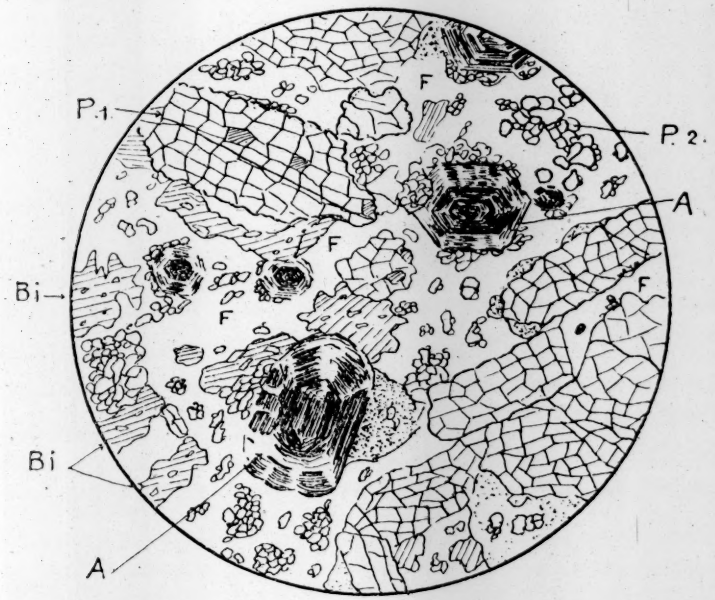

Fig. 3.—No. 217. Mica-enstatite-basalt, approaching an augitite, Tubugwe.
A. Zoned augite, blue-black to violet-black in colour due to inclusions.
P.1. Enstatite, forming irregular composite phenocrysts, sometimes containing a little biotite. Bi. Brown biotite irregular in outline with inclusions of granular pyroxene. P.2. Aggregates of granular pyroxene.
F. Interstitial untwinned felspar, rather in excess in diagram over the actual amount present in the rock.

of enstatite, the outline of which suggests that they are replacements of olivine. The intervening areas are largely composed of untwinned felspar and granular enstatite. The felspar has a refractive index less than that of the Canada balsam; definite determination has not been made, but albite is suggested. The Sp. Gr. is 3·17.

No. 217a. This specimen is similar to No. 217, but contains in addition occasional large, irregular grains of olivine with a reaction rim of enstatite. Various stages are shown to cases where the olivine has been entirely replaced by enstatite. The rock more nearly

approaches the ultrabasic composition and mineral constitution of a limburgite.

No. 221. In this specimen the monoclinic pyroxene phenocrysts are often well twinned, but less frequently zoned: there is no olivine, but its place is taken by areas of finely granular pyroxene, chiefly enstatite and yellowish-brown mica irregularly concentrated round the margin, and less often the mica may preponderate throughout the aggregate. In the clear interstitial areas there is much granular pyroxene, and the felspar is finely granular.

Associated with the Tubugwe rocks in the field there is found a moderate amount of jasper, opaline silica, and carbonate material replacing both the igneous rock and the surrounding gneisses. One interesting example shows a pyroxene-bearing gneiss almost completely silicified, but still showing remnants of the original pyroxene. These rocks represent a later hydrothermal stage now almost extinct, following the igneous intrusion, but represented by a cold spring rising close by.

About 2 miles to the south-west on the Mpapwa track there is a striking occurrence of common opal, brown and yellow in colour, occurring in parallel bands or veins in the gneissic rocks with a bearing of 110 degrees (magnetic). The opal is crowded with small grains and prisms of fluor-apatite, which show definite hexagonal outline and have an attractive blue and bluish-green colour. The formation of these veins is no doubt associated with the hydrothermal period of the Tubugwe intrusions, but the abundance of apatite is an unusual feature.

The Tubugwe rocks are clearly related to the limburgites [1] and augitites [2], both of which types have been recorded from a number of localities along the Rift Zone both in this Territory and in Kenya Colony.

The abundance of brown mica, reaction rims and associated features, the absence of nepheline, melilite, or ægirine-augite, as in some of the augitites, however, is a noteworthy characteristic of the Tubugwe rocks, in contrast to limburgites and augitites of Eastern Africa. The above features, however, associate them with the peridotites of the region under description. Rocks of this nature have been much less frequently referred to in previous petrological descriptions of this portion of Africa. An olivine rock, described as consisting of olivine, diallage, and picotite, is briefly referred to by Finckh [3] as coming from Kaita Mgoi Hill on the south-east Masai Steppe. This locality is about 30 miles north-west from Mgera. It is, therefore, relatively close to the region under consideration, but the petrological description is too brief for close comparison.

[1] L. Finckh, "Die von F. Jaeger in Deutsch Ost-Afrika gesammelten Gesteine": *Mitt a.d. D. Schutzgeb., Ergänz.* No. 4, 1911, pp. 71–85.

[2] Miss A. T. Neilson, in Gregory, op. cit., p. 403.

[3] L. Finckh, "Die von F. Jaeger in Deutsch Ost-Afrika gesammelten Gesteine": *Mitt a.d. D. Schutzgeb., Ergänz.* No. 4, 1911, pp. 71–85.

The hornblende-hypersthene-peridotite from Losilwa Hill, Taveta, described by Hatch [1] and referred to by Gregory [2] as cortlandtite, differs from the peridotite of this region in showing some banding; the hornblende is a green variety, there is no mica, enstatite, or reaction rims, and a highly coloured hypersthene is present. The freshness of the rocks as a whole is another noteworthy feature.

The notable features of these rocks, most particularly the reaction rims and the mineral succession from olivine to pyroxene to hornblende to biotite, and occasionally to felspar, admirably illustrates a discontinuous reaction series in accordance with the views recently expounded by N. L. Bowen.[3] Concerning the age of the Kaguru and Nguru intrusions there is, unfortunately, no direct evidence. By their chemical, mineralogical, and structural features, they are related to one another, but differ somewhat from hitherto described types from East Africa. They show no indication of uralitization or other features in common with the older dolerites (diabases) of the central plateau. With the exception of one case where serpentinization was somewhat marked, they are all remarkably fresh. It is reasonable, therefore, to assume that they represent a Tertiary and probably late Tertiary intrusion. On the assumption that this region represents a horst, the somewhat advanced stage of the erosion cycle would demand a period for its first fractures and dislocation considerably anterior to the late Rift movements, but the igneous intrusions of the region most probably took place at a later date along one of the old lines of weakness.

The mica-bearing peridotites at first sight may suggest a relationship with the well-known kimberlite of South Africa, which has now been recognized as far north as the eastern Belgian Congo.[4] Wagner remarks on the almost identical character of the Belgian Congo rock with that of South Africa. The above rocks from Tanganyika Territory, like those of the Congo, are noteworthy for their reaction rims, but the garnet is only found in one instance, and that is not comparable in occurrence with the typical kelyphitic pyrope of the true kimberlite.

Serpentinization is rare, and perovskite, which is abundant in the Congo rocks, is absent in the Tanganyika rocks. No diamonds have yet been recorded from this area, though it may be significant that the streams draining from this region discharge their waters into the Indian Ocean in the vicinity of the Bagamoyo Coast, where there appears to be an authentic record of the discovery of an uncut diamond.

Apart, therefore, from the scientific interest attached to tracing out the areas and relationships of this rock, the region is worthy of closer investigation from an economic point of view.

[1] F. H. Hatch, op. cit., p. 257.
[2] Gregory, op. cit
[3] N. L. Bowen, "The Reaction Principle in Petrogenesis": *Journ. of Geol.*, vol. xxx, 1922, pp. 177–98.
[4] P. A. Wagner, *S. African Journ. Sci.*, vol. xvii, 1921, pp. 179–81.

4. The Rufiji Valley.

The portion of the Rufiji Valley here referred to lies about 90 to 100 miles inland in a straight line westerly from the mouth of the river which here intersects a relatively low hill region of Karroo rocks, and flows through a narrow rocky canyon cut in flat-lying hard sandstones. It then emerges rather suddenly on to the plains as a wide stream bordered by swamps. The isolated hill of Luhembero lies about 10 miles to the south-east. It consists of an outlier of the Karroo sediment rising above a low plain of loose superficial deposits.

It was here, as previously mentioned, on the north-west side of the hill, that Bornhardt noted the dykes of basalt, phonolite, and andesite, with a bearing of 140 degrees.

During the course of a geological survey of the Karroo rocks of this region by the author, assisted by Mr. F. B. Wade, it was recognized that the 140 degrees (magnetic) bearing is a dominant fault and fracture direction throughout this area. It is further emphasized by the fact that intense brecciation with subsequent silicification and deposition of brown jaspery silica has frequently taken place, which assists materially in the tracing of many of the faults. Strong springs, some of which are still hot and have deposited notable sinter terraces of carbonate of lime, still arise along several of these faults. The earlier hydrothermal phase was a siliceous one. Another fracture-direction of importance, but of less frequent occurrence, has a bearing of approximately north-north-east. This direction marks the boundary of the sediments and the gneiss, and where two faults with this bearing intersect those of the other direction, hot springs occur. One instance is that of Maji-ya-Weta hot spring, a few miles to the south-west from Kisaki. The other is the group of hot springs close to Lake Tagalala, south-east from Behobeho. During a traverse on the southern side of the Rufiji River, Mr. Wade found some loose pieces of a porphyritic phonolite at a point within a few miles of the river and in a direct extension of the Luhembero dykes. Where the further production of the line crosses the Rufiji Gorge there is one of the most marked fracture zones of the district. The hard sandstones are much shattered, and have been affected by hydrothermal action. The amount of the throw of the fault is not ascertainable, but since the massive sandstones occur on both sides of the fracture zone, the vertical displacement is probably not more than several hundred feet at the outside, and may be much less. This fault has not been traced much further, but if it continues, it would pass near the western base of Mount Hatambulo (Mount Johnston), a prominent isolated eminence in the centre of this region, and the highest point. Though neither Bornhardt [1] nor I were able to find the igneous rock from this locality recorded by Thomson [2], it is a likely place to expect it. To the east of

[1] Bornhardt, op. cit., p. 344.

[2] J. Thomson, *To the Central African Lakes and back*, 1881.

TABULAR REVIEW OF BASIC AND ULTRABASIC ROCKS.

No.	Locality.	Felspar.	Olivine.	Pyroxene. Monoclinic.	Pyroxene. Rhombic. Enstatite.	Pyroxene. Rhombic. Hypersthene.	Hornblende.	Biotite.	Garnet.	Spinel.	Reaction Rims.	Type of Rock.	Remarks.
115	Umba	—	—	A	—	—	M	S	—	—	—	Augitite allied to Camptonite	Magnetite. A. Interstitial ? analcite.
97	West Usambara	Andesine. A.	—	—	A	A	S	—	—	—	—	Norite	
98	West Usambara	—	—	S	—	A	S	—	—	—	—	Pyroxenite	Hypersthenite variety.
59	Kaguru-Nguru Region	—	A	A	M	—	—	—	—	—	—	Peridotite Family.	Epidote. Yellow-brown biotite and similarly coloured hornblende noteworthy.
63	Kaguru-Nguru Region	—	A	M	—	M	M	M	—	—	—	Peridotite Family.	Much serpentinized. Yellow-brown biotite and similarly coloured hornblende noteworthy.
64	Kaguru-Nguru Region	—	A	—	M	S	M	M	—	—	—	Peridotite Family.	Not ,, epidote. Yellow-brown biotite and similarly coloured hornblende noteworthy.
83	Kaguru-Nguru Region	—	A	M	M	S	M	M	—	M	C	Peridotite Family.	Green spinet. Yellow-brown biotite and similarly coloured hornblende noteworthy.
84	Kaguru-Nguru Region	—	A	M	M	S	M	M	—	—	C	Peridotite Family.	No spinet. Yellow-brown biotite and similarly coloured hornblende noteworthy.
188	Kaguru-Nguru Region	Anorthite. S.	M	A	A	—	—	—	M	—	C	Peridotite Family.	Basic nouts. Yellow-brown biotite and similarly coloured hornblende noteworthy.
195	Kaguru-Nguru Region	—	A	A	M	—	M	M	—	—	C	Peridotite Family.	Yellow-brown biotite and similarly coloured hornblende noteworthy.
197	Kaguru-Nguru Region	—	A	A	M	—	M	M	—	—	C	Peridotite Family.	Yellow-brown biotite and similarly coloured hornblende noteworthy.
217	Tubugwe	? Albite. M.	S	A	M	—	—	M	—	—	Im	Enstatite-basalt	Zoned pyroxene phenocrysts conspicuous.
217*a*	Tubugwe	,, M.	M	M	A	—	—	M	—	—	M	—	Approaches limburgite.
221	Tubugwe	,, M.	—	M	A	—	—	M	—	—	M	—	,, ,,

A = abundant. M = present in moderate amount. S = sparse or subordinate.
C = conspicuous feature. Im = imperfectly developed.

the mountain several parallel faults with the 140 degrees bearing occur ; one with marked brecciation and silicification and disturbance of adjoining beds. Close at hand there are cold springs with noteworthy calcareous terraces.

The portion of the Rufiji region here considered, lying between the Rufiji in the south and the Mgeta plains in the north, may be regarded as a much fractured, dislocated, and eroded block, forming a portion of a much larger area of Karroo rocks down-faulted against the gneiss to the west and disappearing easterly under younger marine Jurassic and later sediments. Regarding the age of this faulting, there is again no definite evidence ; north-north-east faults intersect the marine Jurassic rocks on the Central Railway to the east of Negerengere. Further south there is no direct evidence beyond the fact that the faults are post-Karroo. The earliest fractures may easily be early Cretaceous or older, but the igneous dykes, in part of an alkaline character, recall types well represented along the Rift Zone, and this together with the present hot spring phase indicates that deep-seated disturbances were renewed at a much later date, though the actual differential movement of strata may not have been great at this period.

The phonolite collected by Mr. Wade (No. 313) is a markedly porphyritic rock with numerous lath-like phenocrysts of sanidine up to 5 mm. long, showing no orientation, and set in a light green base. In ordinary transmitted light, long narrow cloudy phenocrysts of sanidine are abundant, vivid green idiomorphic crystals of ægirine, and cloudy rectangular and hexagonal sections of nepheline. A second generation of smaller crystals of the same kind fills in most of the intervening space, in which also there are not infrequently rectangular prismatic plates of a clear biaxial mineral, with smooth surface, prismatic cleavage, straight extinction, and polarization colours corresponding to muscovite. A similar clear mineral is also present, uniaxial and with lower polarization colours, and is most probably cancrinite. The felspar shows Carlsbad twinning, but is cloudy, due to decomposition. The ægirine is fresh and shows a low extinction angle. Iron minerals are rare. The Sp. Gr. is 2·59.

I desire, in conclusion, to thank Dr. Prior and Mr. W. Campbell Smith, of the Natural History Museum, for their interest in the specimens and advice concerning their comparison with other East African rocks in the Museum collection.

A Foraminiferous Clay at Bredwardine, Herefordshire.

By the Rev. H. E. Grindley, M.A., F.G.S.

HALF a mile above Bredwardine Bridge on the Wye, 11½ miles above Hereford, the river on the right bank runs at the foot of an exposure of drift about 50 feet high, showing the following section: Clayey red sand with sandstone pebbles, subangular; lower 10 feet, more clayey with limestone and claystone pebbles, striated.

This section forms part of the sheet of glacial drift that lies at the foot of Merbach Hill. At the south end of the section the drift curves away from the river and forms a well-marked bank overlooking the flood plain, which rises about 12 feet above the summer level of the river.

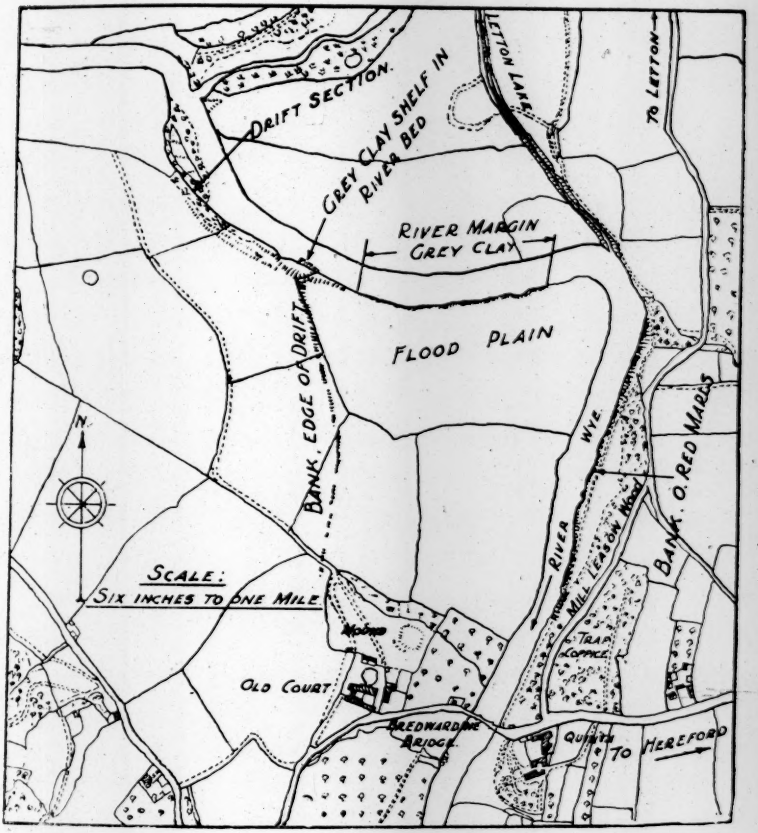

Fig. 1.—Sketch-map, showing position of Drift and Grey Clay above Bredwardine Bridge.

Along the river edge of this flood plain is exposed a remarkable bed of grey plastic clay, very stiff and greasy, and without pebbles. Below the water it forms an abrupt shelf on the river bed, and is traceable at least a quarter of a mile down stream.

Samples of this grey clay and of the red clay of the drift were submitted, in 1905, to Mr. J. Wright, of Belfast, who made the following report :—

"I have now examined the two samples of clay and enclose a list of the microzoa found in No. 1 (grey clay); no specimens were found in No. 2 (red clay from drift). . . . Considering the small amount of clay which I had to examine, the yield of Forams in No. 1 was fairly good: the floatings were alone examined, and were taken from the washed material, which weighed only ·07 oz. . . . The Forams are all common, shallow-water forms, and might be found almost everywhere in muddy places off our coast. I should say the clay is one of the latest Pleistocene deposits. The Foraminifera in the drift are very much smaller in size."

"No. 1.—Weight of clay 1·3 oz. troy, after washing ·07 oz. Clay very fine, no coarse material. Foraminifera frequent.

No. 1.—Miliolina subrotunda (Montag). Frequent.
No. 2.—M. seminulum (Linné). Two broken specimens.
No. 3.—Bolivina plicata (d'Orb.). One specimen.
No. 4.—Lagena Williamsoni (Alesek). Rare.
No. 5.—Globigerina bulloides (d'Orb.). One specimen.
No. 6.—Truncatulina lobatula (W. & J.). Very rare.
No. 7.—Rotalia Beccarii (Linné). Very rare.
No. 8.—Nonionina depressula (W. & J.). Very rare.
No. 9.—Polystomella striato-punctata (F. & M.). Rare.
No. 10.—P. macella (F. & M.). One specimen.
No. 11.—Ostracods.
No. 12.—Mollusca.
No. 13.—Bryozoa.

"No. 2 (red clay).—Weight of clay 1·6 oz. troy; after washing, fine ·07 oz., coarse ·08 oz. No Foraminifera."

On 12th October, 1922, I again went over the ground, and came to the conclusion that the grey clay underlying the flood plain is resting against the bank of drift and does not pass under it. Detritus from the drift has, in places, been washed down into the clay and mixed with the upper layers.

The top of the drift bank is 237 feet O.D., the height above river summer level 50 to 60 feet estimated, the surface of the flood plain about 12 feet above the river. The outcrop of the grey clay may, therefore, be roughly estimated at 189 feet O.D. The thickness of the clay is unknown, as the base lies under water.

Specimens of a similar clay from Breinton on the Wye, 2 miles above Hereford, were submitted to Mr. Wright at a later date. This clay was also obtained from the river bed at about 150 feet O.D. Besides specimens of Nos. 5, 6, 7, 8, and 9 in the above list, Mr. Wright found Haplophragmium Canariense (d'Orb.), Patellina corrugata (Will.), Discorbina obtusa (d'Orb.), Difflugia, and Diatoms. The weight of clay examined was 18 oz. troy, very fine and very dirty, with vegetable matter.

The sketch-map, fig. 1, indicates the position of the grey clay at Bredwardine.

REVIEWS.

THE UPPER CRETACEOUS GASTROPODS OF NEW ZEALAND. By OTTO WILCKENS. New Zealand Geological Survey, Palæontological Bulletin No. 9, pp. v, 1–42, 2 text-figs., plates 1–5, and locality map, Wellington, 1922.

THE mollusca of the Upper Cretaceous of New Zealand show affinities with the Indian-South Pacific Senonian fauna, already well known from Chile, South Patagonia, Grahamland, and Southern India (Ariyalúr Group). There is also a similarity in the lithological nature of the deposits and in the mode of preservation of the fossils. Mr. Henry Woods has dealt with the lamellibranchs and cephalopods (N.Z. Geol. Surv. Pal. Bull. No. 4, 1917), and his conclusions as to the stratigraphical position of the faunas are endorsed in the present study. Most of the shells were collected from localities in Marlborough and Canterbury, and of the twenty-five forms described nineteen are new species.

Two new genera—*Procancellaria* and *Protodolium*—are instituted for forms regarded as ancestors of genera well known from the Tertiary. *Procancellaria* (type, *P. parkiana* sp.n.) has the general shape and cancellate sculpture of *Cancellaria*; the aperture also is similar, but the folds of the columella and of the outer lip are not developed. Similarly *Protodolium* (type, *Neritopsis speighti* Trechmann, GEOL. MAG., 1917, p. 300) resembles *Dolium* in shape, in the coarse spiral sculpture and the form of the aperture, but the channel is not developed. As Dr. Wilckens points out, no true *Dolium* has yet been found in the Cretaceous, but references to J. de C. Sowerby's *Dolium* (*Min. Con.* v, p. 34) are still made in literature, although this shell has been referred to other genera by d'Orbigny and by Pictet and Campiche. Perhaps the most interesting among the gastropods described is the indigenous *Conchothyra parasitica* (McCoy MS.) Hutton, a very heavy semi-globular shell, in which the last whorl covers the earlier ones. In the adult stage this shell is composed of numerous layers, of which the margins are upturned; and, as these margins correspond to the shape of the wing (being curved forwards in the middle and sharply recurved above and below), the surface of the shell is occupied largely by growth-laminae. As an example of gerontic lamination this form is comparable with the common *Gryphæa arcuata* of the European Lias. Although young forms of *Conchothyra* are described, its exact relationship to *Pugnellus* has yet to be determined.

Among the new species, those of typically Cretaceous genera are *Perissoptera waiparaensis* (Hector MS.) and *P. novo-seelandica*, *Struthiolariopsis similis*, *Cryptorhytis vulnerata*, and *Eriptycha punamutica*. In addition to the Upper Senonian species, Dr. Wilckens describes a few shells from the Utatúr Group (Vraconnian

stage) of the Middle Clarence Valley, as well as *Turritella solitaria* sp.n., from beneath the Amuri limestones at Hapuka River (Marlborough) and *Pleurotoma otagoensis* sp.n., from Hector's Cretaceo-Tertiary of Shag Point (Otago). Several of the determinations of gastropods described by C. T. Trechmann (GEOL. MAG., 1917) are here revised.

Although its title gives no indication, this memoir includes descriptions of the annelids *Tubulostium ornatum* (Hector MS.) and *Serpula wharfensis* sp.n., and a doubtful crustacean fragment (*Hoploparia ?*). We must also note that the Director of the Survey (P. G. Morgan) in a footnote (p. 32) proposes the name *Pecten woodsi* for *P. hectori* Woods (N.Z. Geol. Surv. Pal. Bull., No. 4, p. 26), preoccupied by Hutton.

C. P. C.

DESCRIPTION DE LA FAUNE SILURO-DÉVONIENNE DE LIÉVIN. By J. GOSSELET, C. BARROIS, M. LERICHE, A. CRÉPIN, P. PRUVOST and G. DUBOIS. Mémoires de la Société géologique du Nord. Vol. VI (II), Part 1, 1912; Part 2, 1920 (distributed in 1922). pp. 225, 17 + 2 plates, 10 tables and 11 figs.

IN the Pas-de-Calais Coalfield of Northern France there is a region where Devonian rocks have been thrust northwards over the productive Coal Measures. Along a narrow strip of this region, running from east to west under the village of Liévin and between the now-famous little towns of Lens and Vimy, Silurian rocks also are found between the thrust plane and the Devonian. The whole Palæozoic massif is covered by Cretaceous strata but, thanks to a number of coal-mine shafts, the interesting Siluro-Devonian beds have been adequately exposed. A fauna of 102 species is described in the present memoir and the fish-remains have been dealt with elsewhere by Leriche. The first part—comprising the Trilobites and Molluscs—by the four first-mentioned authors, appeared in 1912. The second part—comprising the Brachiopods, etc., and the General Conclusions—is by Barrois, Pruvost and Dubois, and the whole work is thus the joint production of the members of the Geological Laboratory of Lille University. There is more than a hint of sadness in the brief introduction to the second part, where Professor Barrois refers to the death of Gosselet and to the events of the past few years.

The description of fossils occupies 161 pages, and a very valuable feature—unfortunately, far too rare—is that every species described, not merely the new species, is figured.

The Siluro-Devonian succession at Liévin is unique in that it exhibits an uninterrupted *marine* series from definitely Silurian beds—of the age of the Aymestry Limestone—to beds with a predominantly Devonian fauna. In this respect Liévin differs from the Ardennes, where the base of the Devonian is marked by an extensive unconformity; from the Welsh Borderland, where the

highest Silurian strata are succeeded by beds of an abnormal (Old Red Sandstone) facies; and from Devon and Cornwall, where the junction is obscure. After deciding, on carefully-marshalled palæontological evidence, exactly where the junction between the Silurian and Devonian should be drawn in this uninterrupted marine series, the authors proceed to compare other regions. It is significant that recent work in England, carried out along other lines, entirely supports the authors' conclusion that the Ludlow Bone-bed must be taken as the base of the Devonian (Old Red Sandstone facies), thus reverting to Murchison's original limit and satisfying the laws of priority. In the Ardennes, Dumont's original (1848) lower limit of the Rhénan (Devonian)—marked by the unconformity at the base of the Gedinnian—is restored. In the Introduction to the present part, Professor Barrois refers to Professor Leriche, one of the original collaborators, who "prenant les devants, avait publié ses vues personelles sur les relations des faunes de Liévin-Mondrepuits". It will be remembered that Leriche has assigned a Silurian age to the Schistes de Mondrepuits in the Ardennes and the Downtonian in Shropshire. Strongly opposed by many, he has been followed by certain geologists in Belgium and by at least one in this country. It is to be hoped that this memoir, detailed, clear, well-illustrated, and authoritative, will go far towards settling the disputed question of the Siluro-Devonian junction.

One does not need to be reminded of the troubles in the printing trade since the War, and the present part has been in proof for more than two years. The authors must have been weary of seeing proofs, and perhaps for that reason typographic errors are somewhat numerous in places, especially in the references to English literature. In Table X the thickness of the Red Downtonian should be 450 m., not 45 cm., and the upper limit of the Silurian (Murchison, 2nd manner, 1845) was drawn at, or towards, the base of these beds, not above them.

L. D. S.

THE MINERAL RESOURCES OF BURMA. By N. M. PENZER, Federation of British Industries; Intelligence Department. pp. viii + 176, with maps and figures. London: G. Routledge & Sons, Ltd., 1922. Price, 31*s.* 6*d.*

UNTIL recently, as the reviewer well knows by painful experience, it has been extremely difficult to obtain accurate and detailed information as to the mineral resources of Burma, although these are both numerous and important, including such outstanding features as the tungsten ores of Tavoy and the Bawdwin mines, besides the principal ruby deposits of the world. In this book Mr. Penzer has set out to remedy this state of things, and he has fulfilled his purpose very well. The book is written in an interesting style, with an occasional judicious excursion into bypaths of historic interest. The accounts given of the resources of the mineral

products, and the present state of their development, appear to be complete and accurate, with a sufficiency but not an excess of statistics. There is a bibliography of 442 items, which should be of great value. A little more care might well have been exercised in proof-reading, and the price of the book seems exceedingly high, even for these days. It is, however, an excellent piece of work, and should prove most useful to economic geologists.

GOVERNMENT OF THE GOLD COAST: REPORTS ON THE GEOLOGICAL SURVEY FOR THE YEAR 1921. Accra, 1922. pp. 12.

THIS report contains an account of various traverses made by the geologists during the year. Between Prahsu and Dunkwa were seen rocks of the Birrim series, comprising mica-schists, phyllites, slates, sandstones, grits, and quartzites, with dykes of diorite and amphibolite and patches of quartz, the general strike being N.E.–S.W. or E.N.E.–W.S.W.; dips are high and several folds are indicated, while there are signs of metamorphism by a granitic intrusion. Between Nkroforo and Axim were found great masses of andesite, apparently belonging to the Birrim series and invaded by acid intrusions. Oil is found in the sands on the N. side of the Domini lagoon, and a fossiliferous limestone in the same region is believed to be of post-Tertiary age. Thick deposits of bauxite, some of good quality, have been found, derived from phyllites and fine mica-schists. Gold appears to be abundant in many of the gravels, being derived from numerous quartz reefs, and two small diamonds have been discovered.

WESTERN AUSTRALIA. Annual Progress Report of the Geological Survey for the year 1921. pp. 60. Perth, 1922.

DURING the year work was somewhat restricted by changes of personnel and other unavoidable causes. This report gives a general account of work carried out since 1896, with a summary of problems still awaiting solution. This section contains a useful synopsis of the mineral resources of the State. A series of appendices comprise more detailed notes on various questions recently investigated, including borings for coal, petroleum prospects, and examination of deposits of gold, lead, manganese, and asbestos. The results of two searches for oil in the Fitzgerald River district and in the Kimberley division have proved very disappointing, no real indications being found.

POLARIZATION PHENOMENA OF CERTAIN FLUORITES. By A. L. PARSONS. American Mineralogist, Vol. VII, 1922, pp. 142–3.

EXAMINATION of prisms of fluorite for determination of the refractive index by the method of minimum deviation showed that the refracted ray is not polarized, while the reflected ray is almost completely polarized. Hence it is concluded that fluorite is

not singly refracting like glass, but doubly refracting with $\alpha = \beta = \gamma$. The writer of this note has always maintained that it is incorrect to employ the term isotropic in dealing with the optical properties of cubic crystals generally, this usage being inconsistent with the modern use of the word isotropic. Cubic crystals possess many vectorial properties, including crystal-form, cleavage, conductivity, even hardness. They are, therefore, anisotropic, like other crystalline substances, and a new term is needed to express the fact that, as regards light, all their elasticity axes are similar and the wave-surface everywhere circular in section.

REPORTS AND PROCEEDINGS.

Edinburgh Geological Society.

15th November, 1922.

Mr. T. Cuthbert Day, F.C.S., F.R.S.E., President, in the Chair.

1. "Boring for Water at Craiglockhart." By D. Tait, H.M. Geological Survey.

The bore-hole, 300 feet deep, was made by means of a rotary drill using chilled shot, which brings up a solid core of the rock passed through. Forty-five feet of superficial deposits, mainly lacustrine and boulder clay, were pierced before the solid rock was reached. This rock is mainly sandstone of Upper Old Red Sandstone age; it is much fissured, and the sides of the fissures are coated with calcite. The water flows in a copious stream, and analysis has shown it to be of great purity.

2. "Illustrations of Contact Metamorphism in Strathbogie." By H. H. Read, H.M. Geological Survey.

The types of contact-altered rocks were (1) Pyroxene-hornblende-garnet-granulites, produced from epidiorites and amphibolites; (2) hornblende-bearing rocks from norites; (3) a long series of contact rocks from slates. This series starts with spotted slates, passes through andalusite-cordierite-hornfelses, and finishes at pyroxene-hornfelses.

Among pyroxene-hornfelses, hypersthene-hornfels, a rock type of some rarity, was detected.

3. "Pot Holes of Old Red Sandstone Age." By Dr. Campbell.

Instances of pot-holing of recent and Lower Old Red Sandstone age in basalts at Crawton on the Kincardineshire coast were described and illustrated.

4. "Loess from Spitsbergen and Yunnan." By Dr. Campbell.

A highly calcareous loess from Yunnan was compared with a fluvio-glacial silt from Spitsbergen. Analyses of these deposits were given.

5. Exhibits (*a*) "Rhaetic Fossils from Western Mull." By W. Manson, H.M. Geological Survey; (*b*) "Jurassic Fossils from the Banffshire Boulder Clay." By H. H. Read.